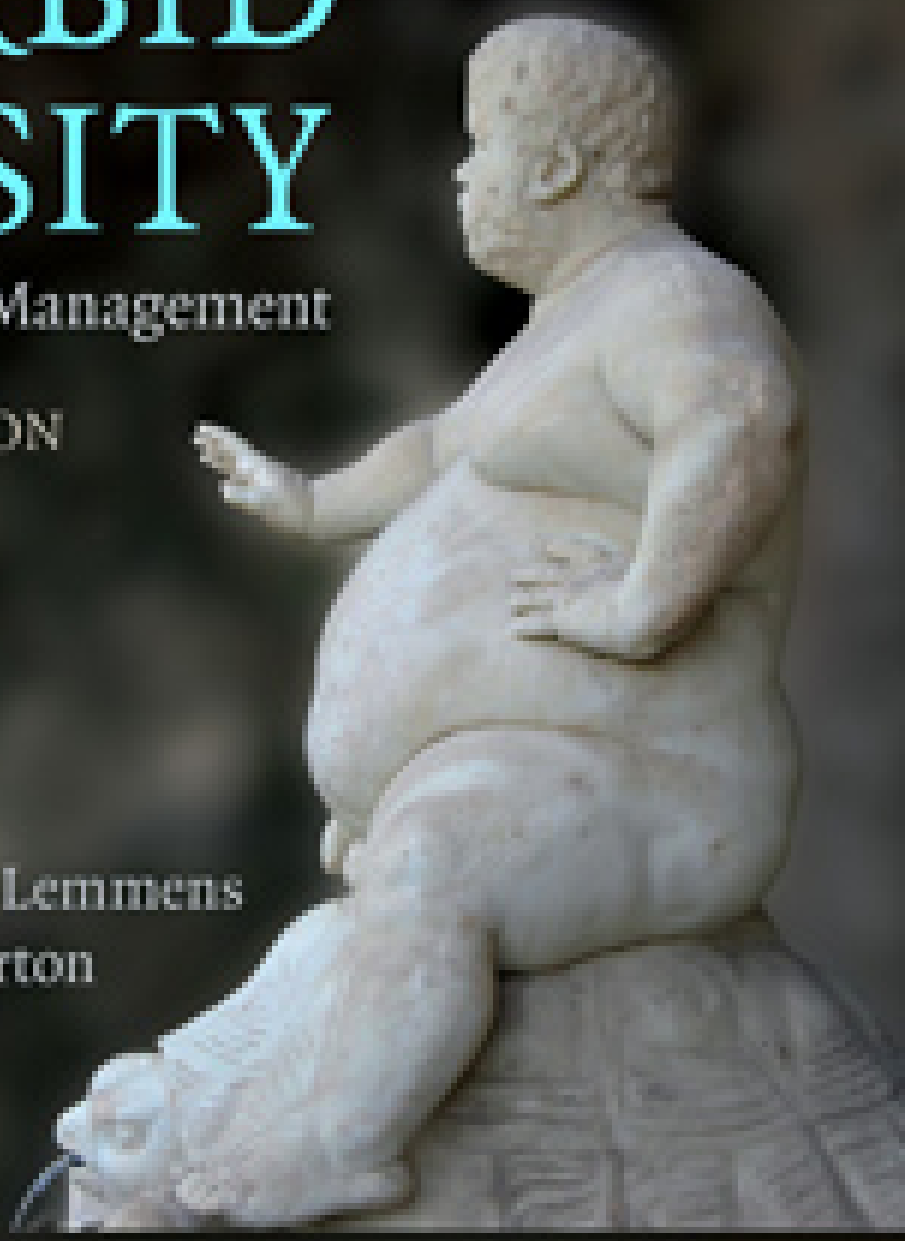
MORBID OBESITY

Peri-operative Management

SECOND EDITION



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Preface to the Second Edition

It has been more than 5 years since the publication of *Morbid Obesity*: *Peri-operative Management*. The book was timely and well received by a wide variety of medical professionals, since it was the first text to consider all aspects of the care of the morbidly obese surgical patient.

Since then obesity has continued to be a worldwide problem. The obesity epidemic has enormously impacted the health resources of countries throughout Europe, Asia, and North and South America. According to a new government report, spending on healthcare for obese American adults increased 82% between 2001 and 2006. The price tag for obesity-related problems is staggering, and includes lost productivity at work, as well as expensive medical treatments, and high costs for prescription drugs. The problems with obesity are overwhelming our health services. In California alone, the economic cost of overweight and obese adults is equivalent to 21 billion dollars annually, a figure that is more than one sixth of the state's total budget.

As predicted when the first edition was published, the number of obese surgical patients continues to grow. This is particularly true for bariatric surgery. According to the American Society for Metabolic and Bariatric Surgery, in the United States more than 1.2 million patients have undergone bariatric surgery in the past decade, with more than 220 000 bariatric procedures performed just this past year.

The vast number of surgical procedures performed on obese patients since the previous edition of this book has contributed steadily to our medical knowledge. Surgical and anesthetic techniques have evolved since 2004, as have pre-, intra- and post-operative care techniques required to meet the special needs of obese patients. An updated, revised book encompassing this new knowledge is certainly indicated. Since much of the information on extreme obesity and surgery comes from extensive experience of bariatric procedures, a large part of this edition is devoted to bariatric surgery, and the lessons learned from that discipline. However, these lessons can and should be applied to any obese patient undergoing any surgical procedure.

For this edition of *Morbid Obesity: Peri-operative Management* an expanded team of editors has joined Adrian Alvarez. This edition is more concise and contains fewer chapters than the first edition, but every chapter concerns itself specifically with the problems of obese and morbidly obese surgical patients. The organization of the book continues to follow patients from their pre-operative assessment and preparation, to their intra-operative surgical and anesthetic management, and then with their post-operative care. Every chapter is authored by experts on the subject matter of that chapter. New chapters have been added (e.g., Pathophysiology of the Pneumoperitoneum, Rhabdomyolysis) reflecting important new information not readily available or widely known in 2004 for the first edition. Other chapters have been consolidated. For example, the previous three chapters on cardiac patho-physiology and cardiac disease are now considered in one chapter, and four chapters on anesthetic agents are now summarized in a single chapter. Additional chapters on some of the very special perioperative areas for obese patients (Informed Consent, Bariatric Surgery in Adolescents) are now included or expanded.

Since obesity is a worldwide problem, this book is intended for an international audience. We believe that surgeons, anesthetists, internists, nutritionists, nurses, psychologists, and anyone else involved in the perioperative management of the obese patient will find this book useful and return to it often as a resource to aid in the care of these complex, often challenging patients. The editors are grateful to the many contributors who have shared their knowledge with the readers.

Adrian Alvarez, Buenos Aires, Argentina
Jay B. Brodsky, Stanford, California
Hendrikus J. M. Lemmens, Stanford, California
John M. Morton, Stanford, California
July 2009

Preface to the First Edition

There is a global epidemic threatening the health of people throughout the world. That epidemic is "obesity." Whereas at one time the problems of obesity were confined to only wealthy industrialized countries, today the incidence of obesity is rising in both developed and developing countries. Obesity-related medical problems are now even affecting the children of those countries. The International Obesity Task Force (IOTF), a collaborative program of the International Association for the Study of Obesity (IASO) and the World Health Organization (WHO) recently estimated that over 1.7 billion people are either overweight (body mass index, BMI > 25kg m^{-2}) or obese (BMI > 30kg m^{-2}).

Obesity is associated with many medical comorbidities including type 2 diabetes, hypertension and cardiovascular disease, respiratory problems and obstructive sleep apnea, arthritis on weight-bearing joints, liver and gallbladder disease, and several types of cancer. In addition there are "quality of life" issues that are of great importance but which cannot be quantified.

These obesity-related health problems have major implications for the individual, and have an enormous impact on the health resources of every country. The costs of obesity are staggering and threaten to overwhelm health services everywhere. The incidence of obesity in the adult population of the USA rose from 14.25% in 1978 to over 31% in 2000. One in five Americans now has a BMI > 30 kg/m^2, and at the current rate that figure is expected to double to 40% by 2025. In 1990 it was estimated that 46 billion dollars, or 6.7% of all healthcare costs, were spent on obesity-related health problems in the USA. Today, those costs are much higher.

The precursors of obesity are multifactorial. They include genetic tendency, environmental effects, education, sex, race and socioeconomic status. There is no precise definition of when obesity begins. A person is usually considered to be obese when the amount of their body fat increases beyond the point where physical health deteriorates. Extreme obesity, that is, obesity that if untreated significantly shortens the individual's life expectancy is termed "morbid obesity." In the USA one out of 16 women is "morbidly obese." The World Health Report for 2002 estimated that there were more than 2.5 million annual deaths due to weight-related problems, with 220 000 of those deaths in Europe and more than 300 000 obesity-related deaths in the USA.

The obesity epidemic reflects changes in behavioral patterns, including decreased physical activity and over-consumption of high-fat foods. There are simple solutions to the problem – early education, sensible long-term diets, increased physical activity and exercise, and in some cases medications. Unfortunately, these easy answers are usually not practical. Therefore, healthcare providers must turn to the only treatment of extreme obesity that is effective – bariatric surgery.

The United States National Institutes of Health Consensus Panel (Gastrointestinal Surgery for Severe Obesity. Consensus Development Conference Panel) convened surgeons, gastroenterologists, endocrinologists, psychiatrists, nutritionists and other healthcare professionals in 1991 to consider the treatment options for severe obesity. That panel recommended that patients first be treated in a program that integrates a dietary regimen, appropriate exercise, behavior modification and psychologic support. If these non-surgical interventions failed, as they usually do, then vertical banded gastroplasty and gastric bypass should be considered. Bariatric surgery today with a wider range of acceptable procedures remains the only effective treatment for patients with morbid obesity.

Bariatric surgery is a cost-effective alternative to no treatment. Surgery is associated with sustained weight loss for patients who uniformly fail non-surgical treatment. Following the weight loss there is a high cure rate for diabetes and sleep apnea, with significant improvement in other complications of obesity, such as hypertension and osteoarthritis. It is estimated that nearly 200 000 bariatric surgical procedures will be performed in the USA in 2004.

Everyday, every anesthesiologist must be ready to deal with morbidly obese surgical patients. Since morbid obesity is present in such a high percentage of the general population, it is also not unusual to be presented with them for non-bariatric surgical procedures. In my own practice at a major university medical center, I estimate that at least 25% of our routine surgical patients are obese and at least 10% of all patients are morbidly obese.

The global nature of the problem is reflected in the worldwide growth of interest in this problem. The International Federation for the Surgery of Obesity (IFSO) now holds a well-attended annual meeting, and the organization has a membership that includes over 30 national bariatric surgical organizations and members from 53 countries. The journal *Obesity Surgery*, now in its second decade, is dedicated to the field of bariatric surgery. So why have we not had a book on the anesthetic management of these patients?

The risks associated with anesthesia and surgery are believed to be higher for obese patients than for normal weight patients. Every anesthesiologist and surgeon must be prepared to safely manage these patients. That requires an understanding of the pathophysiology of obesity and its associated medical problems. The only book I could find dedicated solely to the anesthetic management of obesity is a small monograph (*Anesthesia and the Obese Patient* in the *Contemporary Anesthesia Practice Series*) edited by Brown and Vaughan and published over 20 years ago. Obviously, the techniques of anesthesia and surgery (laparoscopy, epidural opioids, total intravenous anesthesia, etc.) have changed markedly over the past two decades.

When Dr. Alvarez first approached me and asked me to contribute to this book, I was both pleased and honored. A comprehensive book dealing with the anesthetic management of the morbidly obese patient is long overdue. This book covers all areas of anesthesia for the morbid obese surgical patient, from pre-operative evaluation and preparation to intra-operative and post-operative management. The authors, all experts in their respective areas, present the most up-to-date information in their chapters. The international group of the contributors emphasizes the international scale of the obesity epidemic. The reader is encouraged to use this book as a guide and a reference, and continue to follow the medical journals and the internet for the rapidly developing changes in the field of anesthesia for the obese patient.

We are all indebted to Dr. A.O. Alvarez for bringing this important project to fruition.

J.B. Brodsky
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December 2003

Abbreviations

A_aDO_2	alveolar–arterial differences in oxygen tension
ABW	adjusted body weight
ACE	angiotensin converting enzyme
ACS	American College of Surgeons
ADH	antidiuretic hormone
AF	atrial fibrillation
AHI	apnea/hypopnea index
AI	apnea index
ALI	acute lung injury
ALT	alanine aminotransferase
APC	drotrecogin alpha
APGARS	acute post-gastric reduction surgery
ARB	angiotensin receptor blocking agent
ARDS	acute respiratory distress syndrome
ARF	acute renal failure
ASA	American Society of Anesthesiologists
ASMBS	American Society for Metabolic and Bariatric Surgery
AVF	abdominal visceral fat
BIPAP	bi-level positive airway pressure
BIS	bispectral index
BMI	body mass index
BP	blood pressure
BPD ± DS	biliopancreatic diversion, duodenal switch
BPD	biliopancreatic diversion
BSA	body surface area
BV	blood volume
CAD	coronary artery disease
CHD	congestive heart disease
CHF	congestive heart failure
CI	confidence interval
CMS	Centers for Medicare and Medicaid Services
CO	cardiac output
COPD	chronic obstructive pulmonary disease
CPAP	continuous positive airway pressure
CPK	creatine phosphokinase .
CPR	cortisol production rate
CRP	C-reactive protein
CSF	cerebrospinal fluid
CT	computed tomography
CVD	coronary vascular disease
CVP	central venous pressure
DBP	diastolic blood pressure
DHF	diastolic heart failure
DIC	disseminated intravascular coagulation
DO_2	oxygen delivery
DS	duodenal switch
DT	deceleration time of the E wave
DVT	deep venous thrombosis
DWCF	dosing weight correction factor
ECG	electrocardiogram
EF	ejection fraction
EMG	electromyogram
EPIC	European Prospective Investigation into Cancer and Nutrition
$ETCO_2$	end-tidal CO_2
ERV	expiratory reserve volume
FDA	Food and Drug Administration
FEV_1	forced expiratory volume in 1 s
FFA	free fatty acids
FFM	fat-free mass
FiO_2	fractional inspired oxygen concentration
FRC	functional residual capacity
FVC	forced vital capacity
GB	gastric band
GERD	gastroesophageal reflux disease
GFR	glomerular filtration rate
GJ	gastrojejunal
HDL	high density lipoprotein
HELP	head-elevated laryngoscopy position
HFNEF	heart failure with normal ejection fraction
HI	hypopnea index
HR	heart rate
HRQoL	health related quality of life
HTN	hypertension
IAP	intra-abdominal pressure
IBS	irritable bowel syndrome

IBW	ideal body weight
ICP	intracranial pressure
ICU	intensive care unit
IDF	International Diabetes Federation
IDS	intubation difficulty scale
IL	interleukin
IM	intra-muscular
IP	intra-peritoneal
IPC	intermittent pneumatic compression
IR	insulin resistance
IV	intravenous
IVC	inferior vena cava
IVF	intravenous fluid
JCAHO	Joint Commission on the Accreditation of Healthcare Organizations
LAGB	laparoscopic adjustable gastric banding
LBBB	left bundle branch block
LBW	lean body weight
LDL	low density lipoprotein
LFT	liver function test
LGB	laparoscopic gastric bypass
LMA	laryngeal mask airway
LSG	laparoscopic sleeve gastrectomy
LV	left ventricle
LVEDP	left ventricular end diastolic pressure
LVEDV	left ventricular end diastolic volume
LVEF	left ventricular ejection fraction
LVH	left ventricular hypertrophy
LVM	left ventricular mass
MAC	monitored anesthesia care
MAP	mean arterial blood pressure .
ME	mechanical efficiency
MetS	metabolic syndrome
MO	morbidly obese
MPI	myocardial performance index
MRI	magnetic resonance imaging
MVO_2	mixed venous oxygen saturation
NAFLD	non-alcoholic fatty liver disease
NASH	non-alcoholic steatohepatitis "fatty hepatitis"
NCEP	National Cholesterol Education Program
NDNMB	non-depolarizing neuromuscular blocking agent
NIS	Nationwide In-Patient Sample
NO	nitric oxide
NREM	non-rapid eye movement
NSAIDs	non-steroidal anti-inflammatory drugs
OHS	obesity hypoventilation syndrome
OSA	obstructive sleep apnea
OS-MRS	obesity surgery – mortality risk score
$PaCO_2$	partial pressure of arterial carbon dioxide
PACU	post anesthesia care unit
PAI-1	plasminogen activator inhibitor-1
P_{ao}	airway opening pressure
PaO_2	partial pressure of arterial oxygen
PAOP	pulmonary artery occluded pressure
PAP	pulmonary artery pressure
PCA	patient controlled analagesia
PCIA	patient controlled intrathecal analgesia
PCP	primary care physician
P_{crit}	critical opening pressure
PD	pharmacodynamics
PDPH	post-dural puncture headaches
PE	pulmonary embolism
PEEP	positive end-expiratory pressure
PEI	end-inspiratory pressure
$P_{et}CO_2$	end-tidal carbon dioxide
PH	pulmonary hypertension
PIP	peak inspiratory pressure
PK	pharmacokinetics
POD	post-operative day
PONV	post-operative nausea and vomiting
PPAP gamma	gamma peroxisome proliferator-activated receptors
PPH	primary pulmonary hypertension
PPI	proton pump inhibitors
PPV	pulse pressure variation
PSG	polysomnography
$P_{tc}CO_2$	transcutaneous carbon dioxide tension
$P_{tc}O_2$	transcutaneous oxygen tension
PV	pressure-volume
QTc	QT interval
RAAS	renin-angiotensin-aldosterone systems
RBBB	right bundle branch block
REM	rapid eye movement
RML	rhabdomyolysis
RV	right ventricle
RV E_m	diastolic
RV S_m	RV systolic
RYGB	Roux-en-Y gastric bypass gastric bypass
SaO_2	oxygen saturation
SBO	small bowel obstruction
SBP	systolic blood pressure
SCD	sequential compression device
$ScvO_2$	central venous oxygen saturation
SHF	systolic heart failure
SOS	Swedish Obese Subjects study
SpO_2	oxygen saturation

SR	sinus rhythm
SV	stroke volume
SvO_2	mixed venous oxygen saturation
SVR	systemic vascular resistance
T2D	type 2 diabetes mellitus
TBV	total blood volume
TBW	total body weight
TCI	target-controlled infusion
TEA	thoracic epidural anesthesia
TG	triglycerides
TLC	total lung capacity
TNF-α	tumor necrosis factor alpha
TOF	train-of-four
UGH	upper gastrointestinal hemorrhage
UGI	upper gastrointestinal
UHC	University Health Consortium
US	ultrasonography
V/Q	ventilation perfusion
VA/Q	ventilation–perfusion ratio
VALI	ventilator-associated lung injury
VAS	Visual Analogue Scale
VBC	venous bicarbonate
VBG	vertical banded gastroplasty
VC	vital capacity
V_d	volume of distribution
VLDL	very low density lipoprotein
VO_2	total body oxygen consumption
VT	tidal volume
VTE	venous thromboembolism
WHO	World Health Organization

Section 1
Chapter 1

Pathophysiology
Cardiovascular physiology

Donald P. Bernstein

1.1 Introduction

The metabolic syndrome is associated with cardiovascular deterioration and encompasses a constellation of risk factors, which include excess abdominal visceral fat (AVF), atherogenic dyslipidemia, hypertension, insulin resistance, hyperglycemia, and a pro-thrombotic and pro-inflammatory state [1]. Abdominal visceral fat should be considered an endocrine organ because it secretes hormones and inflammatory bio-active peptides, collectively known as adipokines (adipocytokines). At ideal BMI, adipokines have purely beneficial effects on metabolism, cardiac function, and vascular endothelial well-being. However, as AVF increases in volume, excessive amounts of these hormones and inflammatory adipokines have detrimental effects on a variety of organ systems, including the heart and circulation [2] (Figure 1.1).

Independent of hypertension, obstructive sleep apnea (OSA), coronary artery disease, and type 2 diabetes, excess AVF causes metabolic and structural changes of the heart and peripheral circulation [3]. Hemodynamically, this "cardio-metabolic" syndrome in its early stages is characterized by increased blood volume (BV), stroke volume (SV), cardiac output (CO), and preserved indices of global systolic pump-performance, the most recognized being left ventricular ejection fraction (LVEF). The primary causes of obesity cardiomyopathy are myocardial fibrosis, fatty infiltration of the myocardium, and the inappropriate accumulation of free fatty acids (FFA) and neutral lipids within the cardiomyocytes. Through the process of lipotoxicity, lipid overload causes cellular dysfunction, cell death, and, ultimately, clinically relevant cardiac dysfunction [4]. If untreated, this eventually results in congestive heart failure and premature death [5].

1.2 Adipokines

Traditionally, adipose tissue has been perceived as an inert organ whose sole function is as a repository for storing excess energy in the form of triglycerides. It is now known that AVF secretes hormones beneficial to metabolic well-being, namely leptin, adiponectin, and the inflammatory adipokines [6] (Figure 1.2).

1.2.1 Leptin

In lean individuals, leptin is known to act on the satiety area of the hypothalamus to modulate and suppress appetite. As individuals become obese, leptin assumes a major role in the pathogenesis of obesity-related cardiovascular disease. Increased leptin levels have a direct effect on blood pressure (BP), cardiac remodeling, myocyte contraction, and may be a cause of left ventricular hypertrophy (LVH) [7]. Recent studies suggest that leptin is not only produced by AVF, but also by a variety of tissues, including the heart. Hyperleptinemia, with attendant leptin resistance, is associated with insulin resistance, hyperinsulinemia, hyperglycemia and diabetic dyslipidemia, all harbingers of cardiovascular deterioration.

1.2.2 Adiponectin

Adiponectin is an adipocyte-produced hormone that is totally cardioprotective and is the most abundant known secreted factor produced by AVF. In the liver, adiponectin improves insulin sensitivity, decreases non-esterified fatty acid uptake, while increasing oxidation, and reduces gluconeogenesis. In skeletal muscle, adiponectin stimulates both glucose and fatty acid use [8]. Adiponectin has an array of anti-atherosclerotic effects and protects against endothelial dysfunction by increasing local nitric oxide (NO) production, protects cells from inflammation that result from high glucose levels or tumor necrosis

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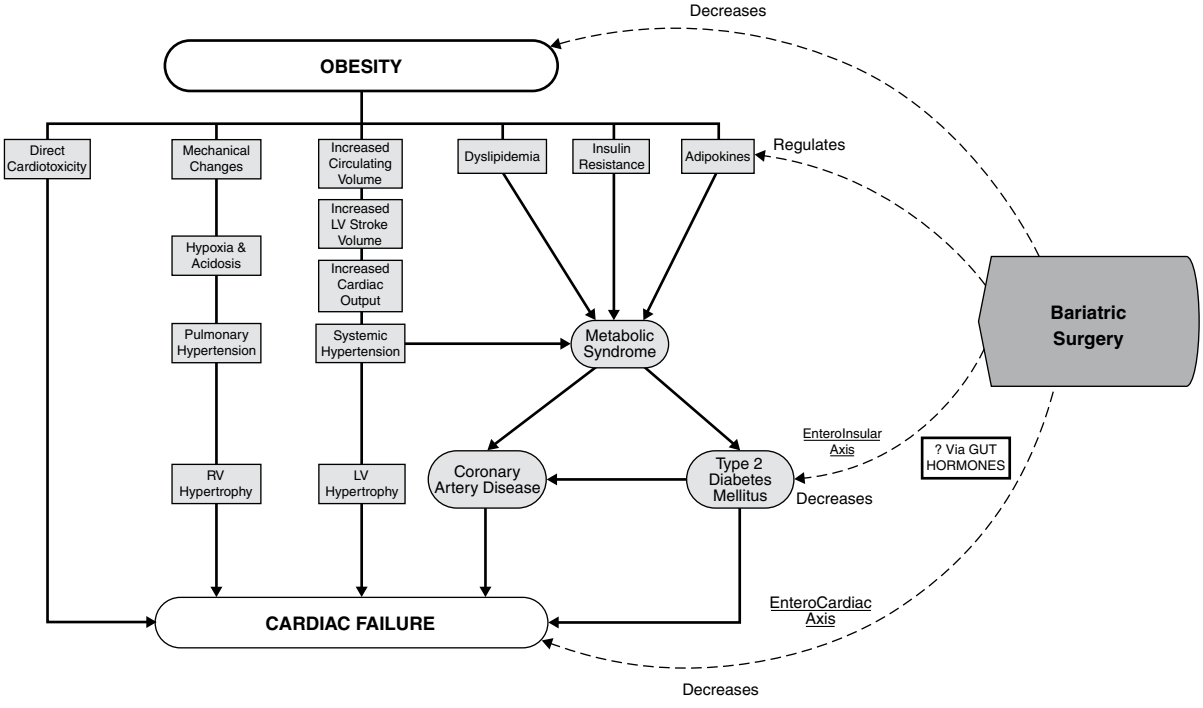

Figure 1.1 Obesity and its consequences leading to cardiac failure. Note the effect of bariatric surgery. RV, right ventricle; LV, left ventricle. From: Ref [66].

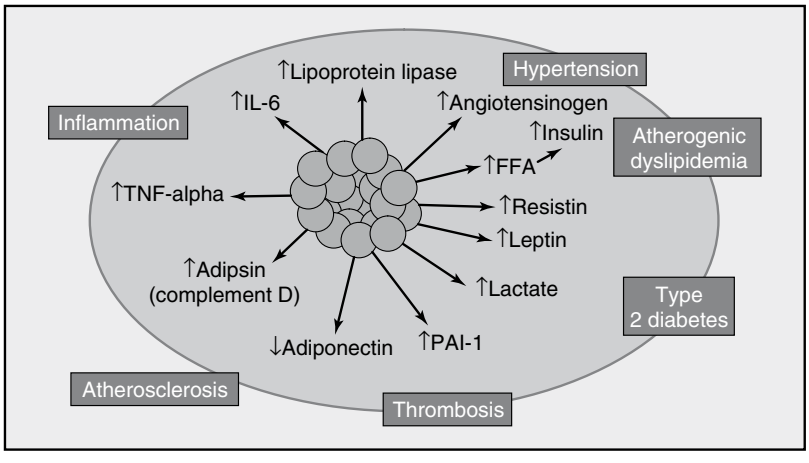

Figure 1.2 Adverse cardiometabolic effects of products of visceral adipocytes. IL, interleukin; FFA, free fatty acids; TNF, tumor necrosis factor; PA-1, plasminogen activator inhibitor 1. From: Ref [2].

factor alpha (TNF-α), while it also inhibits plaque initiation, progression, rupture and thrombosis [9]. In the myocardium, adiponectin-mediated protection from ischemia-reperfusion injury is linked to COX-2-mediated suppression of TNF-α factor signaling and inhibition of apoptosis [10]. With increasing AVF, adiponectin levels decrease and with it, endothelial well-being and the cardioprotective effects of suppression of myocyte hypertrophy, apoptosis, and insulin sensitization.

1.2.3 Inflammatory adipokines

Inflammation, which is normally mediated by inflammatory adipokines, is a protective response of tissue that eliminates noxious agents and debris, and is closely tied to tissue repair. In excess, however, inflammatory

adipokines, through enhanced synthesis of substances such as the potent vasoconstrictor endothelin-1, are responsible for decreased production or availability of NO. This results in small vessel disease, including endothelial dysfunction with attendant dysregulation of vascular tone and vasomotor function [11]. One global marker verifying the presence of the chronic inflammatory state, the primary pathologic mechanism driving the metabolic syndrome, is increased levels of C-reactive protein (CRP) [12]. Thus, at optimal BMI, the inflammatory adipokines serve a useful purpose, but as BMI progresses from overweight to MO these substances have deleterious effects on the heart and circulation [6] (Figure 1.2).

1.2.4 Angiotensinogen

Angiotensinogen, a precursor of angiotensin II, is mainly produced in the liver, but with increasing levels of obesity, angiotensinogen is produced in excess by visceral adipocytes. This provides excess substrate for enzymatic cleavage by angiotensin converting enzyme (ACE) to angiotensin II. Excessive production of angiotensin II provides one of several etiologies causing obesity-induced pressure-overload hypertension with attendant LVH, as well as direct toxicity to cardiac myocytes and vascular endothelium [11].

1.2.5 Plasminogen activator inhibitor-1

Plasminogen activator inhibitor 1 (PAI-1), produced by adipocytes, reduces fibrinolytic activity and induces a pro-thrombotic, hypercoagulable state, which, when venous stasis is present, predisposes to platelet aggregation and adhesion, clot formation, venous thrombosis, and pulmonary thromboembolism [6].

1.2.6 Resistin

Resistin is an AVF-produced hormone that alters cardiac contractility and induces cardiomyocyte hypertrophy. Over-expression of resistin in adult cultured cardiomyocytes significantly alters myocyte mechanics by depressing cell contractility, as well as contraction and relaxation velocity.

1.2.7 Tumor necrosis factor-α

Increased levels of TNF-α appear early in the metabolic syndrome and are a cause of and correlate highly with insulin resistance. They also decrease the bioavailability of endogenously produced NO, which leads to coronary artery and peripheral vascular endothelial dysfunction, and thus, atherosclerosis. TNF-α is highly correlated with the level of CRP, and is thus an early marker of inflammation. It also promotes lipolysis, leading to elevated levels of FFA, thus potentially leading to cardiac lipotoxicity [6].

1.2.8 Interleukin-6

Interleukin-6 (IL-6) is a pleiotropic-circulating adipokine with effects ranging from inflammation to host defense to tissue injury. Plasma IL-6 levels correlate directly with BMI and insulin resistance, and elevated levels of IL-6 predict the development of type 2 diabetes and future myocardial infarction. Increased IL-6 levels are directly correlated with increased plasma FFAs and may also decrease insulin sensitivity by depressing adiponectin secretion.

1.2.9 Other inflammatory substances

Other important toxic proinflammatory products causing endothelial inflammation include interleukin-1β, and interleukin-8. Many other adipokines contribute to insulin resistance, deleterious vasoactivity, dyslipidemic metabolism, and inflammation [7,13]. Figure 1.2 summarizes the adverse cardio-metabolic effects of the adipocytes.

1.2.10 Clinical implications

The maladaptive anatomic and functional cardiovascular changes observed and measured clinically are directly or indirectly a result of dysregulated overexpression of these hormones and other bio-active molecules secreted by excess AVF. Other coexisting pathologies, such as coronary atherosclerosis, type 2 diabetes, systemic and/or pulmonary arterial hypertension, which present before or as a consequence of the cardio-metabolic syndrome, can accelerate the degenerative process.

Weight reduction, by whatever means (lifestyle change, diet, exercise, bariatric surgery), will reverse and ameliorate most of the harmful cardiovascular effects of the adipokines. As a second best line of therapy, current research is focused on drug strategies that will block the deleterious effects of these substances by enzymatic inhibition, or at their target sites [14]. Examples are the use of ACE inhibitors and angiotensin receptor blocking agents (ARBs) to treat angiotensin-induced hypertension and sympathetic discharge, as well as blocking the degenerative processes of the vascular endothelium caused by NO depletion.

Blockade of aldosterone, which, in addition to its effects on reducing intravascular plasma volume, has

been shown to inhibit excessive maladaptive sympathetic discharge as well as the vascular and cardiac fibrosis associated with hyperaldosteronism. Third generation non-selective β-blockers, such as carvedilol, directly suppress β_1-adrenergic-induced tachycardia and maladaptive inotropic stimulation, as well as causing α-1 adrenoceptor antagonism, resulting in arteriolar smooth muscle vasodilatation. Third generation highly selective β-1 blockade, with drugs such as nebivolol, inhibit catecholamine-induced tachycardia and hypertension, as well as promoting NO-mediated systemic vasodilation.

Peri-operatively, the "statin" group of drugs, in addition to their lipid-lowering effects, are known to block the effects of the inflammatory adipokines, thereby improving endothelial dysfunction and large artery stiffness by enhancing NO production. Statins also stabilize endothelial plaques and reduce the incidence of thrombotic episodes by blocking the effects of TNF-α and PAI-1 [15]. Targeting insulin resistance, hyperglycemia, and type 2 diabetes, drugs such as metformin, sulfonylureas, thiazolidinediones, α-glucosidase inhibitors, and insulin alter the progression of the degenerative processes discussed above. The hypercoagulable state, typified by increased levels of PAI-1, is treated by use of platelet inhibitors, such as aspirin and clopidogrel, thereby reducing the probability of arterial and venous thrombosis.

1.3 Pathophysiology and pathogenesis of obesity cardiomyopathy

1.3.1 Global oxygen consumption

Progressive increases in AVF, and especially fat-free mass (FFM) elicit an increased demand for metabolic oxygen. At rest, total body oxygen consumption (VO_2, ml min^{-1}) in the obese and MO exceeds that of individuals at ideal BMI [16]. The rise in VO_2 is directly proportional to the increase in FFM, but not to increased AVF.

Maintenance or augmentation of CO, hemoglobin concentration, and arterial blood oxygen saturation (SaO_2) in the peri-operative period is important in order to optimize oxygen delivery (DO_2). Optimization of DO_2 to meet VO_2 prevents anaerobic metabolism, the consequences of which are metabolic acidosis and depression of myocardial contractility. If CO fails to increase with physiologic stress, such as in severe anemia and/or hypovolemia, oxygen transport becomes inadequate, leading to anerobic metabolism with lactic acidosis and myocardial depression.

1.3.2 Blood volume

Total blood volume (TBV) progressively increases over the full range of BMI, but the relationship is non-linear and not directly proportional to deviation from ideal body weight (IBW) [17]. With progressive deviation from IBW or BMI, indexed BV in ml kg^{-1} actually decreases. Figure 1.3 shows that the decrease in indexed BV is inversely and hyperbolically related to both progressive deviations from IBW and absolute increases in BMI. The mean value for indexed BV in healthy adults of ideal BMI is usually given as 70 ml kg^{-1}, with males and females being somewhat higher and lower by ±5 ml kg^{-1}, respectively. As Figure 1.3 demonstrates, indexed BV at or near ideal BMI (70 ml kg^{-1}) would grossly overestimate BV in the MO patients. The increase in TBV and CO is due to increased metabolic demands imposed by excess AVF and, more importantly, by the increase in FFM [18]. The increase in plasma volume, TBV, and circulating BV is due to both secondary polycythemia and sodium retention via the adipose-derived angiotensinogen-induced increase in aldosterone.

For patients undergoing major surgery, and especially MO individuals, pre-operative estimation of TBV is as important as determining hematocrit and hemoglobin levels. While hematocrit and hemoglobin levels define the percentage of red cells and quantity of oxygen-carrying protein in blood, they provide little insight with regard to the magnitude of TBV and the tightly controlled derivative components: intra-thoracic and global end-diastolic blood volumes. These parameters are highly correlated with ventricular preload, and thus to SV and CO. Clinically, pre-operative over-estimation of TBV, which could easily occur in MO patients using 70 ml kg^{-1} for indexed BV, might lead to under-administration of crystalloids, colloids, and red blood cells in the event of massive fluid translocation and/or hemorrhage.

1.3.3 Stroke volume and cardiac output

Obesity is characterized by a hyperdynamic circulation. At rest CO progressively increases primarily as a function of increasing oxygen demand, which triggers down-regulation of B-natriuretic peptide and up-regulation of aldosterone-induced salt and water retention. In concert with enhanced erythropoesis, circulating BV increases. The increase in CO is due

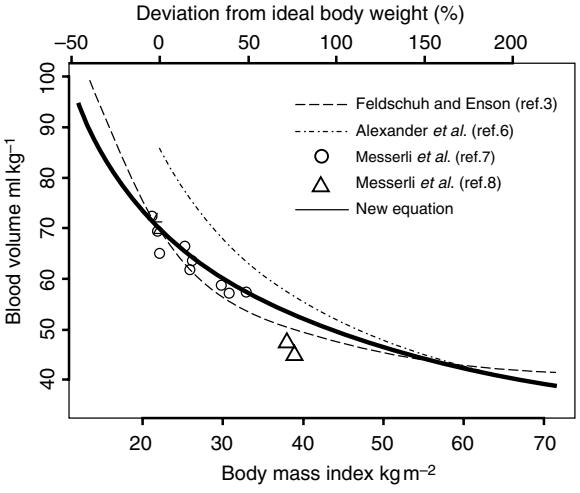

Figure 1.3 The relationship between indexed blood volume (ml kg^{-1}) and deviation from ideal body weight and absolute values of BMI. The relationship is hyperbolic and is described by the equation

$$BV_{ml\,kg^{-1}} = \sqrt{BMI_{patient} / BMI_{idea\,-22kg/m^{-2}}}.$$

The solid line represents the calculated value and the others have been extrapolated from the literature. From: Ref [17].

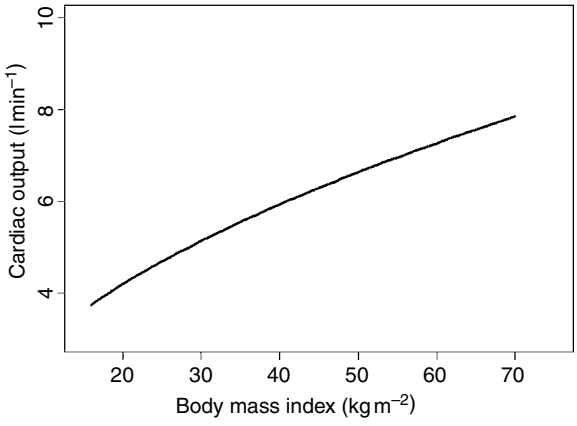

Figure 1.4 The relationship between CO and BMI is not linear. The relationship is described by the equation,

$$CO_{patient} = CO_{idealBMI=23} \sqrt{BMI_{patient} / BMI_{idea=22kg/m^{-2}}}.$$

Note that the calculated values closely approximate the measured values reported by Stelfox *et al.* [19]. Modified from: Ref [19].

almost entirely due to enhanced SV, because over a full spectrum of BMI, heart rate (HR) changes little [19]. Progressive augmentation of SV is principally due to increased left ventricular end-diastolic volume (LVEDV; preload), and to a much lesser extent increased contractility via adrenergic neurohormonal stimulation. When the elevated CO is normalized by body surface area, cardiac index is found to be within the normal physiologic range.

Increases in SV and CO are usually described as being linear and directly proportional to increased BMI. Figure 1.4 shows that CO increases as a function of the square root of normalized BMI. Evidence suggesting that CO is not directly proportional to increased fat mass is implied by the observation that perfusion per unit of adipose tissue actually decreases with increasing obesity. For example, at 15–26% body fat, perfusion per 100 g is 2.36 ml min^{-1}, whereas at greater than 36% body fat, perfusion per 100 g decreases to 1.53 ml min^{-1} [20]. Thus, on a ml kg^{-1} basis, this represents a decrease in overall adipose tissue perfusion of approximately 35%. Using data from Messerli *et al.* [21], where the increase from lean normotensive to obese normotensive yielded a CO increase of 1.67 l min^{-1}, implies that the increase in fat mass does not account for the overall increase in CO. The perfusion deficit is due to increased perfusion of the added FFM.

In the very obese (> 35 kg m^{-2}) and MO (> 40 kg m^{-2}) individual, exercise does not elicit an appreciable increase in SV [22]. This is due to a state of chronic volume overload, maximal wall stress, exhaustion of recruitable preload reserve and reduced contractility. With exercise, the ejection fraction (EF) does not increase, indicating that at a fixed LVEDV, end-systolic volume does not decrease to produce a larger SV [22]. Modest increases in CO are then due almost exclusively to increases in HR. When HR increases during exercise, it is accompanied by supra-normal increases in left ventricular end diastolic pressure (LVEDP) and pulmonary artery occluded pressure (PAOP). Inasmuch as systolic, diastolic, and mean arterial pressure (MAP) do not change significantly at rest in progressive uncomplicated obesity, CO progressively increases as a function of decreased systemic vascular resistance (SVR) [23]. Relatively normal MAP and increased CO imply that the adipose tissue vascular bed, which is added hemodynamically in parallel to the normal vascular tree, is of low resistance, thereby reducing total vascular resistance.

In the peri-operative period, attempts at increasing SV/CO in the MO by increasing HR and/or contractility may lead to increased myocardial oxygen consumption elevated LVEDP, increased pulmonary artery pressure (PAP) and PAOP, without increasing CO significantly. In cases where contractility is deemed depressed (i.e., EF ≤ 40%), afterload reduction with judicious use of low-dose peripheral vasodilators (i.e., nebivolol,

carvedilol, hydralazine), ACE inhibitors, and ARBs should be considered [24, 25]. In acute decompensated congestive heart failure (CHF), calcium-sensitizing inodilators, such as levosimendan, are preferable to dobutamine, because they reduce afterload and increase contractility without increasing MVO_2 [26]. In acute heart failure, other useful vasodilating agents that increase SV and CO by decreasing both afterload and preload include nitroglycerin, nitroprusside, and nesiritide. With the exception of CHF refractory to therapy and/or atrial fibrillation (AF) with rapid ventricular response, use of digitalis as a means to increase contractility should be discouraged, because, as a potent inotrope, it markedly increases MVO_2 and thus may cause myocardial ischemia. Evidence also suggests that third-generation β-blockers, such as carvedilol and nebivolol, improve myocardial contractile function, especially in systolic dysfunction and failure, by up-regulating β-adrenergic receptors (carvedilol) and increasing endothelial NO production (nebivolol), thus inducing vasodilatation, and reducing myocardial oxygen consumption and energy requirements. The use of loop diuretics, such as furosemide, is indicated to reduce pulmonary vascular congestion in the setting of depressed left ventricle (LV) function or frank volume overload.

Treatment of hypovolemia, due to either fluid translocation or blood loss, should be treated cautiously with crystalloids, colloids, and/or red blood cells as the clinical situation dictates. Excessive preload, caused by over-enthusiastic fluid replacement, can result in acute LV chamber dilatation, thereby increasing afterload by increasing wall stress. This clinical scenario can precipitate acute LV failure, independent of obesity cardiomyopathy.

1.3.4 Fat-free mass and left ventricular mass

Increased FFM is highly correlated with increased TBV, SV, and CO independent of linear increases in BMI [18]. Concordantly, left ventricular mass (LVM) is most highly correlated with FFM [27]. Thus LVM is also highly correlated to TBV, SV, and CO.

1.4 Maladaptive ventricular modeling

Histologically, the most common post-mortem finding in obesity is myocyte hypertrophy. Fibrotic changes result in a stiffened, concentrically remodeled myocardium with impaired relaxation and diastolic dysfunction. Vascular changes include perivascular fibrosis of the arterioles within the myocardium.

Obese individuals have increased heart weight. Comparing matched obese populations with normal weight controls demonstrates that MO individuals have greater LVM by almost 50% [28]. The progressive cardiomegaly observed over the full range of BMI in patients without hypertension or type 2 diabetes suggests that cardiac hypertrophy occurs independently of other risk factors [29]. There is evidence to suggest that elevated leptin and resistin levels, as well as sympathetic neurohormonal stimulation and activation of the renin-angiotensin-aldosterone systems (RAAS) may be responsible for LVH in obese individuals. When hypertension and/or nocturnal hypoxemia are associated with OSA, the effect is synergistic with the hypertrophy of obesity alone [28]. While the vast majority of MO patients develop LVH (80%), it is interesting to note that only 30% develop right ventricular hypertrophy [30].

1.4.1 Eccentric hypertrophy

Eccentric hypertrophy is a maladaptive mechanism in response to volume overload. As TBV and CO increase to meet the increased metabolic demands imposed by excess AVF and FFM, left and right ventricular and atrial chamber dimensions, and volumes passively increase to accommodate progressive increases in venous return, end-diastolic volume, and SV. Increases in chamber volume and left ventricular end-diastolic dimensions, without coinciding increase in wall thickness, such as occurs in inadequate eccentric LVH, increases circumferential wall stress. Increasing wall stress augments MVO_2, which, in turn may lead to myocardial ischemia [31]. Eccentric hypertrophy is characterized by an increase in cavity volume that is greater than the increase in wall thickness (Figure 1.5). When eccentric hypertrophy is associated with heart failure, the term dilated cardiomyopathy is commonly used. Earlier studies ascribed the majority of LVH in the MO to be of the eccentric type, but this has recently been challenged [32] (Figure 1.6).

1.4.2 Concentric hypertrophy

Concentric hypertrophy is a maladaptive type of ventricular remodeling characterized by wall thickening that exceeds the rate of chamber dilatation (Figure 1.5). Concentric hypertrophy can evolve purely as a pathologic process of the metabolic syndrome alone, or may result from pressure overload due to systemic hypertension [32]. Inasmuch as hypertension may be present before the advent of the metabolic syndrome, or may result as a complication of the

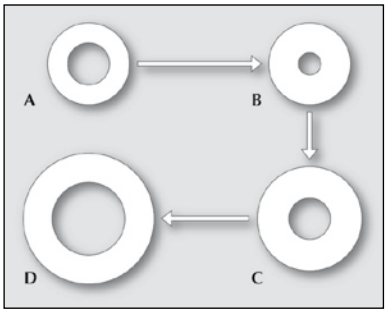

Figure 1.5 Structural remodeling of the left ventricle (LV) with increasing duration and severity of obesity. In the short axis view: A. Normal LV, normal LV mass and relative wall thickness; B. Increased LV concentric remodeling (increased relative wall thickness) without frank LV hypertrophy; C. LV concentric hypertrophy with increased relative wall thickness; D. LV eccentric hypertrophy (increased LV mass with decreased relative wall thickness). From: Ref [37].

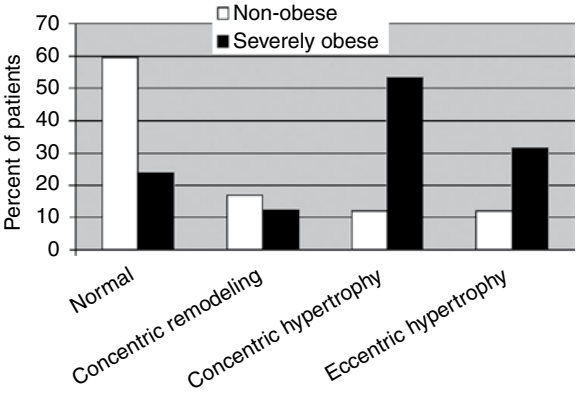

Figure 1.6 Left ventricle (LV) geometry in non-obese and obese patients. Normal LV geometry is the most common in the non-obese referent group, whereas eccentric and concentric LV hypertrophy become more prevalent in severely obese subjects. Concentric hypertrophy is the most frequent pattern in the obese subjects. From: Ref [28].

metabolic syndrome, per se, it is sometimes difficult to distinguish between cause and effect. Intuitively it would appear that concentric hypertrophy would be preferable to the eccentric type, because wall thickening in excess of chamber dilatation would reduce wall stress. The perception that concentric LV remodeling in pressure overload is a compensatory mechanism to reduce wall stress to maintain systolic performance is probably incorrect. Studies have shown that LV function may be normally maintained, even in the presence of elevated wall stress. Paradoxically, reduced wall stress caused by concentric LV hypertrophy is associated with increased cardiovascular risk of death as compared to eccentric hypertrophy [33].

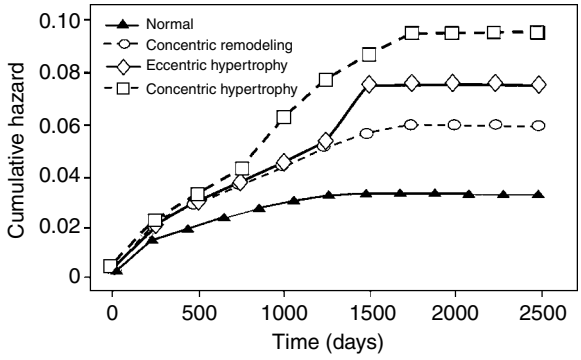

Figure 1.7 Impact of left ventricle geometric pattern on cumulative hazard of death over time in 11 792 obese patients with preserved ejection fraction. Hazard was greatest with concentric hypertrophy and least with normal geometry. Eccentric hypertrophy had a greater hazard than concentric remodeling, but less than concentric hypertrophy. From: Ref [34].

1.4.3 Concentric remodeling

Concentric remodeling relates to a ventricle with echocardiographic evidence of increased relative wall thickness, but does not meet the echocardiographic definition of hypertrophy. Concentric remodeling is by far the most common form of ventricular remodeling in obesity and carries a long-term mortality rate higher than normal ventricular geometry (Figure 1.7).

1.4.4 Pathophysiologic considerations

Concentric hypertrophy, as compared to eccentric hypertrophy, is associated with increased risk of death [34]. The most attractive hypothesis assumes that LVH of the concentric variety subjects the heart to increased susceptibility from subendocardial ischemia by reducing the endocardial to epicardial blood flow ratio (endo/epi ratio). Animal studies demonstrate that concentric LVH subjects the heart to reductions in the endo/epi ratio, but only during periods of hemodynamic stress.

Therapeutic drug strategies specifically targeted at regression of LVH include ACE inhibitors, ARBs, and β-blockade. Recent animal studies show that pressure overload-induced concentric LVH can be prevented by administration of resveratrol, a polyphenol found in red wine [35]. Therapies aimed at improving forward flow (SV) from an hypertrophied left ventricle require modulating increased SV and CO against altered endo/epi blood flow ratio and the mechanical efficiency of the heart. In the hypertrophied heart seen in MO, especially the concentric variety, increasing HR, the most potent stimulus of MVO_2, will increase MVO_2 to

a greater extent than either augmented SV or systolic BP; the net result is reduction in mechanical efficiency (ME) with tachycardia. As concentric LVH becomes progressively worse, ME decreases as a function of the increased MVO_2 required to power the increased LVM. In the MO patient with SV already at near-maximum at rest, increasing HR will accomplish very little except to increase MVO_2. The resulting harmful effect is reduction of ME and the epi/endo blood flow ratio of the heart. This scenario can lead to subendocardial ischemia and permanent damage to an already diseased ventricle. Thus, to increase ME and reduce endocardial wall stress, therapies targeted at reducing afterload (wall stress and systolic BP) and increasing SV, such as with ACE inhibitors, ARBs, and selective and non-selective β-adrenoceptor blockades are the treatments of choice. By reducing afterload, it is most important to prevent diastolic hypotension, especially in LVH of the concentric variety. In light of the differences in coronary reserve, ME, and epi/endo blood flow ratios between eccentric and concentric LVH, determination of the altered geometry should be determined by echocardiography pre-operatively.

1.5 Genesis of obesity cardiomyopathy

Obesity cardiomyopathy, or CHF associated with obesity, can be caused by primary systolic heart failure (SHF), usually associated with eccentric hypertrophy and systolic dysfunction, or, more commonly by diastolic heart failure (DHF), usually associated with concentric hypertrophy or remodeling, and diastolic dysfunction. Simply put, DHF is essentially the inability of the left ventricle to load efficiently, whereas SHF is essentially the inability of the ventricle to unload and pump effectively. Differentiation between SHF and DHF cannot be made on the basis of signs and symptoms, or by chest x-ray or ECG. Diagnosis is made non-invasively by interrogation of the left ventricle using Doppler echocardiography, tissue Doppler velocimetry, or a combination of the two [36].

Insofar as maladaptive geometric remodeling is concerned, there is a continuum, similar to that seen in hypertensive heart failure. As generally accepted, LV concentric remodeling develops first, which then evolves into LV concentric hypertrophy. If concentric hypertrophy-induced diastolic dysfunction does not lead to DHF and death, then, as the duration and magnitude of obesity increases, compensated eccentric LV hypertrophy evolves, which precedes frank dilated cardiomyopathy (i.e., SHF, decompensated eccentric hypertrophy) [37] (Figure 1.5).

1.5.1 Diastolic dysfunction and diastolic heart failure

Diastolic dysfunction is characterized by increased resistance to filling of the left ventricle. This leads to an inappropriate rise in the diastolic pressure–volume relationship, which causes symptoms of pulmonary congestion during exercise (Figure 1.8). Symptoms of pulmonary congestion at rest are characteristic of DHF.

The prognosis of DHF is more ominous than SHF. Predisposing factors for DHF are older age, female gender, diabetes, obesity, arterial hypertension, and concentric LVH [36]. Prevalence of sub-clinical diastolic dysfunction is present in 12% of slightly obese (mean BMI = 29.5 kg m^{-2}), 35% of the moderately obese (mean BMI = 32.4 kg m^{-2}), and 45% of MO individuals (mean BMI = 39.7 kg m^{-2}). When diastolic dysfunction progresses to frank CHF with normal EF, the syndrome-complex is known as DHF, and more explicitly as heart failure with normal ejection fraction (HFNEF). The incidence of DHF represents < 15% of chronic heart failure in patients < 50 years old, 33% in those between 50 and 70 years old, and 70% in those > 70 years old [38].

Diastole encompasses the time period during which the myocardium loses its ability to generate force and shorten and returns to an unstressed length and force. Diastolic dysfunction exists when these processes are prolonged, slowed, or incomplete. In terms of mechanics, the term diastolic dysfunction indicates an abnormality of diastolic distensibility, filling, or relaxation of the left ventricle, regardless of whether the EF is normal or abnormal, and whether the patient is symptomatic or asymptomatic.

Thus, diastolic dysfunction alters the compliance of the LV and ease with which blood flows into the LV during diastole. With diastolic dysfunction, the heart is able to meet the body's metabolic needs, whether at rest or during exercise (albeit with symptoms of congestion), but at a higher LV diastolic filling pressure [38]. Clinically, diastolic dysfunction is present when signs or symptoms of poor exercise tolerance and dyspnea on exertion are associated with laboratory evidence of reduced LV compliance, increased stiffness and LVEDP, despite normal EF and end-diastolic volumes [36]. The transition from concentric hypertrophy and diastolic dysfunction to DHF is thought due to increasing LV

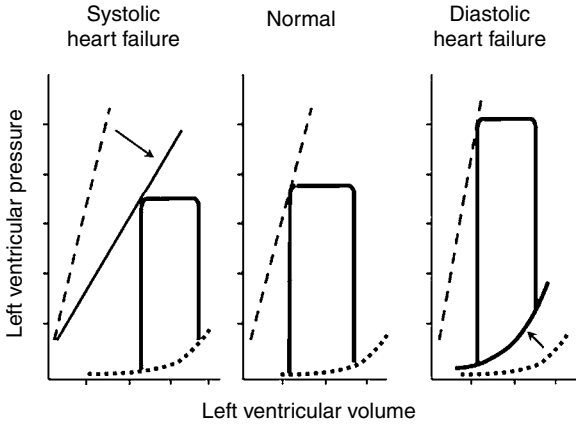

Figure 1.8 Left ventricle (LV) pressure–volume relationship through one cardiac cycle. Normal LV (center) shows normal contractility (dashed line) as evidenced by the normal slope of the end systolic P-V relationship (ESPVR) and normal left ventricular end diastolic pressure (LVEDP; dotted line) and normal left ventricular end diastolic volume (LVEDV; x-axis) at mitral valve opening. Systolic heart failure (left) shows reduced contractility as demonstrated by the reduced slope of the ESPVR (solid line) and increased LVEDP (dotted line) and LVEDV (x-axis) at mitral valve opening. Diastolic heart failure shows normal contractility as evidenced by a normal slope of the ESPVR (dotted line), and markedly increased LVEDP (solid line) at a normal LVEDV (x-axis) at mitral valve opening. From: Ref [39].

fibrosis and enhanced ventricular and aortic stiffness due to aging, as well as to the deleterious adipocytokine effects of MO.

Diagnostically, echocardiographically-derived Doppler early (E) and late (A) mitral diastolic flow velocities (E/A ratio) and timing intervals (isovolumic relaxation time; deceleration time of the E wave, DT) are useful for estimating increased LV stiffness and compliance. However, estimating the magnitude of LVEDP requires obtaining the ratio of the early diastolic mitral blood flow velocity (E) and early diastolic tissue Doppler myocardial velocity (E′) (i.e., E/E′ ratio). Doppler confirmation of both increased LVEDP and left atrial volume index > 40 ml m^{-2} is prima facie evidence, highly diagnostic of the severity of diastolic dysfunction [36]. Unfortunately, in approximately 30% of MO patients a satisfactory acoustic window cannot be obtained. Both pre-and post-operatively, reduction of LVEDP by preload reduction may improve survival in obese patients. The peri-operative goals and strategies for treatment of diastolic dysfunction and DHF are shown in Table 1.1.

Management of acute intra- and post-operative decompensated DHF is primarily aimed at reducing pulmonary congestion and amelioration of precipitating factors, such as hypertensive crisis, myocardial ischemia, acute rhythm disturbances and sepsis. Treatment goals directly aimed at relieving pulmonary congestion involve preload and afterload reduction, which can be achieved by intravenous nitroglycerin, nitroprusside, nesiritide, and/or diuretics. These recently recommended guidelines will reduce venous return and decrease LVEDV, which lead to reductions in LVEDP. No currently clinically available drug provides selective enhancement of myocardial relaxation without inhibiting left ventricular contractility or function. Thus,

Table 1.1 Peri-operative therapeutic strategies for diastolic dysfunction

Pre-operative
• Make a definitive diagnosis of diastolic dysfunction or DHF (history and echocardiography).
• Hypertension: treatment with ACE inhibitors, ARBs, β-blockers and NO inducers.
• Reduction in central blood volume (i.e., preload) by use of diuretics or nitrates to relieve pulmonary congestion and symptoms of heart failure.
• Control heart rate with β-blockers (carvedilol, nebivolol) and calcium channel blockers (diltiazem, verapamil).
• Maintain atrial contraction and treatment of atrial fibrillation (diltiazem, digoxin, β-blockade, amiodarone).
• Statins should be used as they stabilize endothelial plaques and block thrombotic episodes due to TNF-α and PAI-1.
• Mechanical efficiency of the heart should be optimized by use of NO-inducing β-blockers (nebivolol), ACE inhibitors, ARBs, and peripheral α-1 adrenergic blocking vasodilators (carvedilol).
Intra-operative
• Oxygen delivery should be optimized by maintenance of blood volume, hemoglobin concentration, and CO.
• Use of anesthetic agents that do not affect LV diastolic properties (i.e., sevoflurane, desflurane, opioids, muscle relaxants).
• Avoid diastolic hypotension (especially with concentric hypertrophy).
• Treat tachydysrhythmias, and especially atrial fibrillation with rapid ventricular response.
Post-operative
• Prevention and treatment of hypertensive crises will reduce/prevent pulmonary edema.
• Prevention of pain-induced sympathetic activation (tachycardia, hypertension), shivering, hypovolemia, and anemia are therapeutic goals for prevention of myocardial ischemia.
• Continuous positive airway pressure is useful to reduce pulmonary congestion and improve oxygenation, especially in patients with OSA.
• Levosimendan and nebivolol may improve systolic function by combining a vasodilator and positive inotropic effect without increasing MVO_2.

Notes: SHF, systolic heart failure; SV, stroke volume; ACE, angiotensin converting enzyme; ARB, angiotensin receptor blocking agent; CO, cardiac output; NO, nitrogen oxide; MVO_2, mixed venous oxygen saturation; OSA, obstructive sleep apnea.

unlike SHF, where treatment therapy and goals are well defined, current treatment strategies for DHF, with the exception of loop diuretics for pulmonary congestion, have no randomized controlled trial-proven efficacy, and do not address the root causes of diastolic dysfunction and HFNEF, these being reduced ventricular compliance and increased stiffness.

1.5.2 Systolic heart failure: heart failure with reduced ejection fraction

In general, SHF and DHF have two properties in common: increased LV mass (hypertrophy) and increased LVEDP (Figure 1.8). Differentiation of the two is based on the type of geometric remodeling and LV function. In the MO patient, systolic dysfunction and heart failure are generally associated with eccentric hypertrophy and, in contradistinction to DHF, enlarged LVEDV and reduced LVEF [39]. As compensated eccentric hypertrophy transitions to SHF, progressive enlargement of the LVEDV causes the ventricle to become more spherical, and, with insufficient hypertrophy, causes excessive wall stress in both systole and diastole.

1.5.3 Diastolic dysfunction associated with SHF

As is true for DHF, the severity of SHF is closely linked to diastolic dysfunction, regardless of LVEF. Similar to DHF, SHF is associated with abnormal diastolic filling and markedly increased left atrial pressure. These abnormalities are corroborated echocardiographically by tissue Doppler velocimetry. The peri-operative goals and strategies for the treatment of systolic dysfunction and SHF are shown in Table 1.2.

1.5.4 Right ventricular dysfunction and failure: effects of BMI, obstructive sleep apnea, and pulmonary hypertension

A paucity of studies addresses the effect of MO alone on right ventriculer (RV) function. As BMI increases from 23 to 47 kg m^{-2}, and independent of OSA, there is progressively reduced RV function as characterized by decreased RV systolic (RV S_m) and diastolic (RV E_m) tissue Doppler free wall velocities, with no change in right ventricular ejection fraction [40].

When obesity is associated with OSA, right ventricular myocardial performance index (MPI) is increased, indicating that global RV myocardial function is depressed. With weight loss, MPI decreases, demonstrating improvement in RV function [41].

Table 1.2 Peri-operative strategies for systolic dysfunction

Pre-operative
• Make diagnosis of SHF from signs or symptoms and echocardiographically.
• Preload and afterload reduction to relieve pulmonary congestion and enhancement of SV by use of loop diuretics and/or intravenous nitrates.
• Statins to stabilize coronary and peripheral vascular endothelium.
• Block harmful effects of adrenergic stimulation and neurohormonal activation. Drug therapies, which have randomized, controlled-trial proven efficacy, include a combination of the following :
• ACE inhibitors
• ARBs
• β-blockers
• Aldosterone antagonists
• Digoxin for patients who remain symptomatic despite diuretics, ACE inhibitors, β-blockers, calcium sensitizers (levosimendan), and for those with associated atrial fibrillation with rapid ventricular response.
• Cardioversion is suggested when atrial fibrillation is refractory to drug therapy.
• Amiodarone, or amiodarone + $MgSO_4$ are recommended for rate and rhythm control after cardioversion.
Intra-operative
• Maintain or increase CO with α-1 blocking vasodilators, such as carvedilol, or by inodilators such as nebivolol, which causes vasodilation by increased production of endothelial NO.
• Treat tachydysrhythmias to restore normocardia, thus reducing MVO_2.
• Acute decompensated SHF should be treated with levosimendan and/or veno/vasodilators, including nitroglycerin, nitroprusside and nesiritide, but only if patient is considered normovolemic and normo- or hypertensive.
• Inotropic agents, such as dobutamine and milrinone/amrinone, should rarely be used for acute decompensated SHF, except when SHF is unresponsive to selective and non-selective β-blockers, levosimendan and intravenous veno/vasodilators.
Post-operative
• Treat symptomatic SHF with levosimendan, nitroglycerin, nitroprusside, nesiritide and vasodilating β-blockers (nebivolol, carvedilol, bisoprolol).
• Maintain or restore sinus rhythm, especially when patients with atrial fibrillation were pre-operatively on anticoagulants and/or platelet inhibitors.
• Tachycardia should be effectively treated.
• Treat resistant hypertension and/or pulmonary congestion with nitroglycerin, nitroprusside, nesiritide and vasodilating β-blockers.
• Fluid overload should be treated with loop diuretics.
• Continuous positive airway pressure to treat OSA and pulmonary congestion.

Notes: DHF, diastolic heart failure; ACE, angiotensin converting enzyme; ARB, angiotensin receptor blocking agent; NO, nitric oxide; TNF-α, tumor necrosis factor-α; PA1–1, plasminogen activator inhibitor 1; CO, cardiac output; LV, left ventricle; OSA, obstructive sleep apnea; MVO_2, mixed venous oxygen saturation.

Pulmonary hypertension (PH), secondary to hypoxic pulmonary vasoconstriction or left heart failure, results in increased PAP and RV afterload, thereby contributing to development of RV hypertrophy, chamber enlargement, increased RV wall stress, tricuspid insufficiency, and cor pulmonale [42].

Ultimately, severe, chronic PH results in RV failure with reduction in RV SV and CO. RV failure can be defined as the clinical syndrome resulting from the right heart's inability to provide adequate blood flow to the pulmonary circulation at a normal central venous filling pressure. Diagnostically then, RV failure is not present if there is adequate CO and central venous pressure (CVP) is normal. However, if CO is inadequate, CVP is high, RV contractile dysfunction is apparent on imaging studies, pericardial tamponade is not present, and abnormalities of LV function are not sufficient to explain the clinical syndrome, RV failure must be present [42].

Pre-operative assessment of PH is important because intra- and post-operative outcomes may depend on relatively intact RV performance. Specifically, severe reductions in RV SV and CO lead to inadequate LV output, mimicking primary LV failure. The principle therapeutic goals for RV failure generally involve improving RV contractility and right coronary artery perfusion with concomitant reduction of RV afterload. Strategies to reduce PH pre-operatively include calcium channel blocking pulmonary vasodilators, such as nifedipine or diltiazem, endothelin-1 antagonists (e.g., bosentan), pulmonary vasodilators (e.g., epoprostenol [prostacyclin]), and vasodilating phosphodiesterase inhibitors (e.g., sildenafil) [43]. With established RV failure, contractility can be enhanced without increasing MVO_2 by use of the calcium-sensitizing inodilator levosimendan. In the case of right coronary artery hypoperfusion, due to systemic hypotension, norepinephrine has been shown to increase RV contractility by increasing both systolic and diastolic coronary perfusion pressures. To prevent RV failure intra-operatively, fluid overload and excessive peak and positive end-expiratory pressures must be avoided. Acutely induced RV failure is almost impossible to treat satisfactorily, and death is a sure outcome [42].

1.6 Obesity paradox

Obese (30 kg m^{-2} ≤ BMI <40 kg m^{-2}) and MO (BMI ≥ 40kg m^{-2}) individuals who are free of heart failure or overt cardiovascular disease have a higher prevalence of cardiovascular death than otherwise healthy individuals of normal BMI (18.5 kg m^{-2} ≤ BMI < 25 kg m^{-2}), or those who are overweight (25 kg m^{-2} ≤BMI < 30 kg m^{-2}) [44] (Figure 1.9). Paradoxically, however, obese individuals with CHF have much greater 2–5-year survival than CHF patients of ideal BMI or those who are underweight (BMI < 18.5 kg m^{-2}) [45]. Possible explanations for this phenomenon include advanced age and a higher incidence of malnourishment, cachexia, and chronic obstructive pulmonary disease in the underweight patients with CHF [46]. However, when adjustments for the above variables are included in multivariate analysis, overweight and obesity remain protective against mortality [45]. Taken in perspective, these findings should be weighed against the evidence that weight loss improves virtually all aspects of cardiovascular, anatomic, and functional derangements incurred during the obese state and reduces the risk of CHF [46].

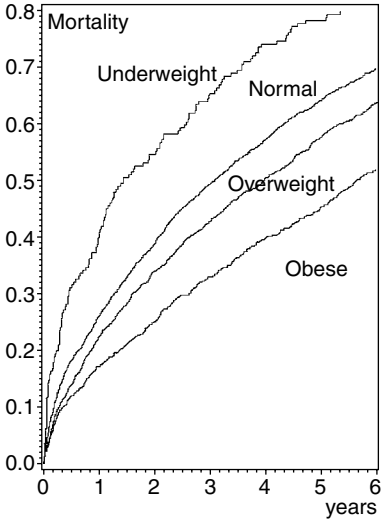

Figure 1.9 Mortality rate in 4700 patients with congestive heart failure (CHF) according to their BMI at baseline. Note that underweight patients with CHF have highest mortality and the morbidly obese with CHF have lowest mortality. From: Ref [46].

1.7 Modifiable pathology associated with morbid obesity

1.7.1 Atrial fibrillation

Atrial fibrillation is commonly associated with MO, and for each unit of BMI increment there is a 3–8-fold greater risk of AF [47, 48]. In obese patients who are ≤ 65 years of age, OSA is independently associated with AF [49]. Atrial fibrillation is also highly associated with consequences of the metabolic syndrome. In concert with increasing BMI, progressive enlargement of left atrial volume is independently and synergistically associated

with progression of paroxysmal AF to permanent AF [50]. The development of AF in the setting of CHF, and the converse, is associated with clinical deterioration and worsening prognosis. Hemodynamically, excessive ventricular rate, shortened and chaotic LV diastolic filling times, and loss of atrial contraction, which can account for 20–40% of SV, portends a poor prognosis compared to patients in sinus rhythm (SR). Conversion from AF to SR improves cardiac function. While there is no argument that AF rate control improves survival when associated with CHF, it is easily assumed that rhythm control would further enhance prognosis. A recently published definitive trial, which attempted to show survival benefit from rhythm control in patients with CHF, reported no improvement in the incidence of cardiovascular death [51].

Pharmacologic strategies designed to minimize MVO_2 and maximize SV and CO, include rate control using β-blockers and digoxin, calcium channel blockers, and amiodarone. In patients with CHF, caution should be exercised in the use of calcium channel blockers as they significantly reduce contractility. In patients with both AF and CHF, rate control with a combination of carvedilol plus digoxin has been shown to improve heart failure symptoms by increasing LVEF. Cardioversion in conjunction with drug therapy is usually initially successful, but generally requires more frequent hospital visits for resynchronization. Newer, minimally invasive procedures, such as atrioventricular nodal ablation with concomitant placement of permanent ventricular or biventricular pacemakers have been shown to increase LVEF and exercise tolerance.

Although it does not improve overall long-term survival, the attainment of regular SR is most probably indicated for MO patients undergoing anesthesia and surgery. Associated benefits from converting AF to SR prior to surgery in the MO include increases in SV of 20–40 and maintenance or augmentation of CO at a lower HR, which improve the ME of the heart and overall oxygen transport to tissues. Control of HR and beat-to-beat diastolic perfusion pressure is critical to prevention of subendocardial myocardial ischemia, especially in patients with concentric LV hypertrophy (*vide supra*). Conversion to SR is especially important in the peri-operative period, because anticoagulation therapy is usually withdrawn pre-operatively. This subjects the obese patient with AF to the risk of systemic arterial embolism, the results of which include infarction of major organ systems, including the brain.

1.7.2 Obstructive sleep apnea

Obstructive sleep apnea has been implicated as a cause of AF, systemic hypertension, PH, stroke, coronary heart disease (CHD), hypercoagulability, left atrial enlargement, and sudden cardiac death during sleep. It is also presumed that OSA may significantly affect myocardial contractility [52]. Hypoxemia, hypercapnia, high negative (sub-ambient) intrathoracic pressure, arousal responses, and fragmented sleep, all caused by frequent episodes of apnea with airway collapse, have been found to enhance cardiovascular adrenergic autonomic activity and promote endothelial dysfunction [53] (Figure 1.10). This leads to increased peripheral resistance and afterload, resulting in sustained systemic hypertension. There is evidence that reduced levels of NO, in conjunction with elevated levels of serum endothelin-1, a potent vasoconstrictor, are etiologic in the genesis of OSA-induced hypertension. In patients with OSA, PH is present in approximately 40% of patients in whom clinically significant cardiac and pulmonary disease is excluded. Etiologically, fixed PH is due to chronic intermittent hypoxic pulmonary vasoconstriction, secondary to repetitive airway collapse and undulating oxyhemoglobin desaturation. As a consequence, progression of PH can lead to *cor pulmonale* with right ventricular failure.

OSA is closely associated with AF and other nocturnal dysrhythmias, such as non-sustained ventricular tachycardia, sinus arrest, second degree atrioventricular block, ectopic ventricular beats, and bradydysrhythmias [54]. Prolonged QT_c interval (HR-corrected QT interval), a commonly reported ECG abnormality in MO, in conjunction with nocturnal hypoxemia, predisposes patients with OSA to a potentially lethal tachydysrhythmia, *torsades de pointes* [55]. In patients without PH and normal EF, increased apnea hypopnea index is independently associated with biventricular impairment. It is interesting to note that, despite the high incidence of OSA in the MO population, only 30% demonstrate RV hypertrophy at autopsy [30].

If OSA is present or suspected pre-operatively, continuous positive airway pressure (CPAP) has been shown to decrease pulmonary artery systolic pressure, reduce the incidence of cardiac dysrhythmias, and enhance cardiac performance in patients with CHF.

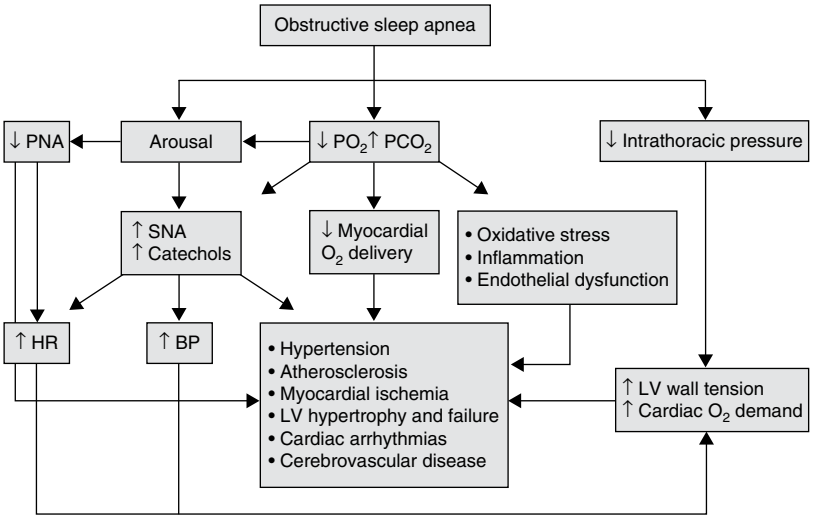

Figure 1.10 Pathophysiologic effects of obstructive sleep apnea on the cardiovascular system. PNA, parasympathetic nervous system activity: PO_2, partial pressure of oxygen; PCO_2, partial pressure of carbon dioxide; SNA, sympathetic nervous system activity; HR, heart rate; BP, blood pressure; LV, left ventricular. From: Ref: [53].

In the post-operative period, the effect of anesthetic agents, opioids, and sedative-hypnotics may precipitate and increase the frequency and magnitude of OSA. Despite assumed efficacy of CPAP, there is insufficient controlled trial evidence substantiating reduction of adverse cardiac events [56].

1.7.3 Hypertension and vascular compliance

Hypertension (BP ≥ 130/85) is common in MO and is due to a constellation of factors. Elevated systolic BP and pulse pressure are independent predictors of vascular stiffening (i.e., loss of compliance), left ventricular hypertrophy, CHD, CHF, stroke, and chronic renal disease.

In MO pulse pressure increases since SV increases with progressive increases in intrathoracic BV, while large artery compliance progressively decreases due to large vessel distension and wall stiffening [57]. Some of the complex pathophysiologic abnormalities linking obesity to hypertension include abnormal sodium handling and natriuretic peptide down-regulation, which lead to increased plasma and BV, leptin resistance, activation of the sympathetic and RAAS, insulin resistance and hyperinsulinemia, and changes in the peripheral vascular system [58] (Figure 1.11). These various and seemingly unrelated parameters ultimately lead to elevated CO and SVR.

Early in the evolution of the metabolic syndrome, and as a consequence of increased BV and reduced SVR, CO increases with MAP remaining within normal limits. Hypervolemia results in increased venous return and increased LVEDV, leading to left ventricular chamber enlargement with compensatory eccentric hypertrophy. Later in the syndrome, and as a result of endothelial dysfunction, increased sympathetic nervous system stimulation, activation of the RAAS, leptin-induced vasoconstriction, insulin resistance, and hyperinsulinemia, hypertension is due to either increased CO, SVR remaining inappropriately normal, or, as is more commonly observed, increased CO with increased SVR. Increased afterload, due to both systemic hypertension and increased LV wall tension (i.e., increased LVEDP), leads to concentric hypertrophy, or a hybrid of both eccentric and concentric remodeling. Inadequately treated hypertension leads to coronary heart disease, kidney failure, stroke, and, ultimately, left ventricular failure.

Patients who present for surgery should ideally be normotensive and normocardic, but these conditions are frequently unmet. Current therapeutic goals are targeted at: (1) blocking sympathetic discharge with α-1 receptor antagonists and selective and non-selective β-1 blockade; (2) blocking the RAAS with ACE inhibitors, ARBs, and aldosterone antagonists; (3) restoring normal large artery and endothelial function by means of NO inducers and "statins"; and (4) reduction of circulating blood volume by means of thiazide diuretics. Control of BP and HR will lower the incidence of perioperative CHF, myocardial ischemia, and infarction.

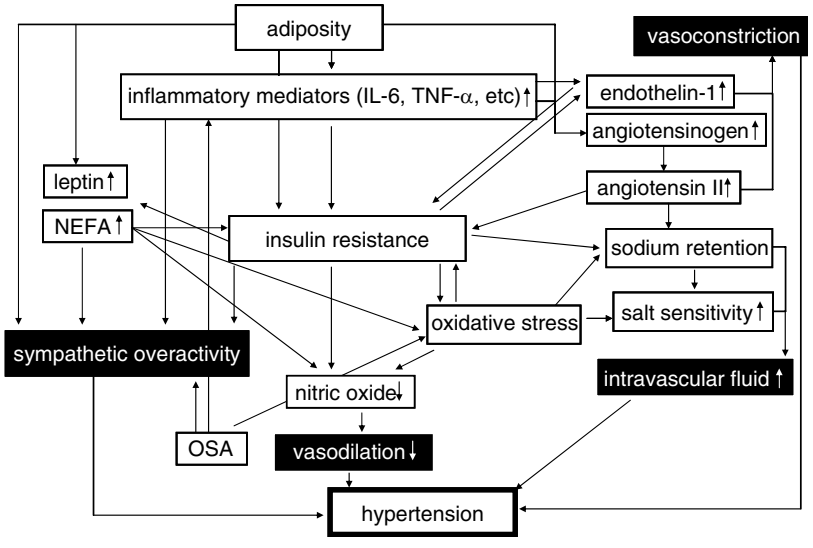

Figure 1.11 Proposed mechanisms for development of hypertension in the metabolic syndrome. IL-6, interleukin-6; NEFA, non-esterified fatty acids; OSA, obstructive sleep apnea; TNF-α, tumor necrosis factor-alpha. From Yanai H *et al.* The underlying mechanisms for development of hypertension in the metabolic syndrome. *Nutr J* 2008; **7** : 10.

In approximately 20–30% of patients, hypertension is resistant to triple drug therapy, including a diuretic. Approximately 20% of these patients have hyperaldosteronism and may benefit from mineralocorticoid receptor antagonists, such as spironolactone or eplerenone [59].

1.7.4 Insulin resistance, diabetes mellitus type 2, and cardiac dysfunction

Excess AVF is commonly associated with insulin resistance, impaired glucose tolerance, and type 2 diabetes. Type 2 diabetes is associated with the genesis of atherosclerosis, CHD, stroke and, independent of MO, commonly results in insulin resistant cardiomyopathy [60]. Abdominal obesity is accompanied by a state of chronic low-grade inflammation, characterized by increased production of pro-inflammatory adipokines, which play a role in the development of atherosclerosis and insulin resistance. Production of TNF-α and IL-6 is increased. In a state of oxidative stress, TNF-α induces insulin resistance by disrupting cellular glucose uptake and allowing FFAs to predominate as the preferred substrate for conversion to ATP, this being the necessary fuel for myocardial contraction [61]. Preferred oxidation of FFA over glucose leads to increased MVO_2 and, regardless of LVM or HR, leads to decreased ME and diastolic dysfunction [62]. Elevated FFA levels are also associated with reduced vascular endothelium-dependent vasodilatation, increased hepatic gluconeogenesis, decreased insulin-mediated skeletal muscle glucose uptake, and, in the short term, hyperinsulinemia. The myocardium normally responds to injury by altering substrate metabolism from FFA to glucose oxidation, which increases energy efficiency. Insulin resistance prevents this adaptive response, which can lead to lipotoxicity, sympathetic up-regulation, inflammation, oxidative stress, myocardial fibrosis, and diabetic cardiomyopathy [60]. Inasmuch as non-ischemic diabetic cardiomyopathy, unassociated with MO is common, and non-ischemic obesity cardiomyopathy is generally associated with insulin resistance, the two entities can be considered nearly identical etiologic pathways to the same disease end-point: heart failure.

1.7.5 Coronary heart disease, atherogenesis, and the cardio-metabolic syndrome

The relationship between obesity and CHD has been a contentious subject for many years [63]. Since obesity is associated with risk factors, such as dyslipidemia, insulin resistance, a pro-inflammatory and pro-thrombotic state, the question is not if obesity is associated with CHD, but to what extent. This question has not been successfully answered, because other factors, including genetics, gender, level of physical activity, OSA, and cigarette smoking can act in a positive or negative manner to alter the direct relationship between obesity and CHD [64].

Peri-operative care of the MO individual (especially those < 50 years of age) should consider that the

majority suffers from some degree of CHD, and a vast majority have ventricular hypertrophy. Thus, avoidance of tachycardia is most important from the standpoint of reducing MVO_2. Increased wall stress induces endocardial ischemia (even in the absence of CHD); therefore, afterload from both increased LV end-diastolic pressure and systemic arterial systolic hypertension should be minimized. If CHD is associated with left ventricular dysfunction and pulmonary congestion, loop diuretics are indicated. Ischemic heart failure associated with CHD should be treated with the inodilating β-blockers and/or the calcium sensitizers. Excessive preload should be treated with diuretics and/or nitrates.

1.7.6 Electrocardiographic abnormalities and dysrhythmias

Voltage magnitudes and axes of the P, QRS and T waves can be abnormal in obese individuals [65]. Despite LVH, QRS voltage has been found to be variably increased or decreased, showing that ECG criteria for LVH in the MO are not sufficiently specific or sensitive enough for definitive diagnosis. Coronary heart disease is common in MO and ST-T wave abnormalities, ST segment depression and T wave inversion are frequently encountered. Leftward shifts of the P, QRS and T wave axes are common and probably related to the leftward and more horizontal orientation of the heart secondary to diaphragmatic pressure from excess AVF. The axis changes are directly linked to the severity of obesity and have been found to be reversible with weight loss. Apart from relatively benign increases in the PR interval, the most clinically significant ECG findings are increases in the QRS and QTc intervals. Increases in QRS duration may eventuate into right or left bundle branch block (RBBB, LBBB) or left anterior hemiblock with RBBB (bifascicular block). There is an association of LBBB with ventricular asynchrony, interventricular septal bulge into the left ventricular cavity during right ventricular systole and decreased LV SV. Increased QTc interval is associated with potentially lethal ventricular tachydysrhythmias, such as *torsades de pointes*, which probably accounts for many of the unexpected nocturnal deaths in MO individuals. Common *post-mortem* findings in patients with OSA and sudden death include cardiac hypertrophy, ventricular septal bulge, focal mononuclear cell infiltration in and around the sinus node, fatty infiltration throughout the conduction system, fibrosis of the AV node, and coronary atherosclerosis.

1.8 Improvement after weight loss and bariatric surgery

Surgically induced weight loss reverses many of the maladaptive functional and structural cardiovascular changes associated with MO and reduces overall risk [66] (Figure 1.1). Electrocardiographic abnormalities are substantially reversed [66]. In addition to favorable axis shifts and resolution of LVH, bariatric surgery substantially shortens the prolonged QTc interval, thus reducing the incidence of fatal ventricular tachydysrhythmias (i.e., *torsades de pointes*) [55]. The most consistent echocardiographic findings are significant reductions in LVM and, apart from regression of left ventricular hypertrophy, no other echocardiographic parameters show consistent improvement.

LV systolic function, as assessed by LVEF, demonstrates improvement only if systolic function is markedly depressed before surgical intervention [67]. In studies of otherwise healthy MO patients, midwall fractional shortening, another systolic contractility index, showed no change post-operatively [68]. Hemodynamically, weight loss is accompanied by reductions in TBV, which, by virtue of reduced VO_2, result in diminished levels of SV and CO [69]. As a consequence of substantial reductions in CO and unchanging MAP, SVR increases. As a result of reduced intrathoracic BV and LVEDP, PAP and PAOP decrease with weight loss. These beneficial changes can be quite substantial when MO is associated with PH [70]. Left ventricular diastolic function improves, as demonstrated by reduced LV stiffness and LVEDP. Right ventricular function also improves after bariatric surgery with improved RV diastolic tissue Doppler myocardial velocities and decreased MPI [41, 71]. Endothelial function also improves after weight loss due to increased levels of adiponectin, and diminished levels of CRP and leptin [12].

References

1. Despres JP, Lemieux I, Bergeron J, *et al*. Abdominal obesity and the metabolic syndrome: contribution to global cardiometabolic risk. *Arterioscler Thromb Vasc Biol* 2008; **28**: 1039–49.
2. Rosin BL. The progression of cardiovascular risk to cardiovascular disease. *Rev Cardiovasc Med* 2007; **8** Suppl 4: S3–8.
3. Wong C, Marwick TH. Obesity cardiomyopathy: pathogenesis and pathophysiology. *Nat Clin Pract Cardiovasc Med* 2007; **4**: 436–43.

4. Wang J, Song Y, Wang Q, *et al*. Causes and characteristics of diabetic cardiomyopathy. *Rev Diabet Stud* 2006; **3**: 108–17.
5. Peeters A, Barendregt JJ, Willekens F, *et al*. Obesity in adulthood and its consequences for life expectancy: a life-table analysis. *Ann Intern Med* 2003; **138**: 24–32.
6. Hajer GR, van Haeften TW, Visseren FL. Adipose tissue dysfunction in obesity, diabetes, and vascular diseases. *Eur Heart J* 2008; **29**; 2959–71.
7. Perego L, Pizzocri P, Corradi D, *et al*. Circulating leptin correlates with left ventricular mass in morbid (grade III) obesity before and after weight loss induced by bariatric surgery: a potential role for leptin in mediating human left ventricular hypertrophy. *J Clin Endocrinol Metab* 2005; **90**: 4087–93.
8. Harmancey R, Wilson CR, Taegtmeyer H. Adaptation and maladaptation of the heart in obesity. *Hypertension* 2008; **52**: 181–7.
9. Szmitko PE, Teoh H, Stewart DJ, Verma S. Adiponectin and cardiovascular disease: state of the art? *Am J Physiol Heart Circ Physiol* 2007; **292**: H1655–63.
10. Ouchi N, Shibata R, Walsh K. Cardioprotection by adiponectin. *Trends Cardiovasc Med* 2006; **16**: 141–6.
11. Zhang C. The role of inflammatory cytokines in endothelial dysfunction. *Basic Res Cardiol* 2008; **103**: 398–406.
12. Manco M, Fernandez-Real JM, Equitani F, *et al*. Effect of massive weight loss on inflammatory adipocytokines and the innate immune system in morbidly obese women. *J Clin Endocrinol Metab* 2007; **92**: 483–90.
13. Rabe K, Lehrke M, Parhofer KG, *et al*. Adipokines and insulin resistance. *Mol Med* 2008; **14**: 741–51.
14. Krentz AJ. Prevention of cardiovascular complications of the metabolic syndrome: focus on pharmacotherapy. *Metab Syndr Relat Disord* 2006; **4**: 328–41.
15. Schindler C, The metabolic syndrome as an endocrine disease: is there an effective pharmacotherapeutic strategy optimally targeting the pathogenesis? *Ther Adv Cardiovasc Dis* 2007; **1**: 7–26.
16. Seres L, Lopez-Ayerbe J, Coll R, *et al*. Cardiopulmonary function and exercise capacity in patients with morbid obesity. *Rev Esp Cardiol* 2003; **56**: 594–600.
17. Lemmens HJ, Bernstein DP, Brodsky JB. Estimating blood volume in obese and morbidly obese patients. *Obes Surg* 2006; **16**: 773–6.
18. Collis T, Devereux RB, Roman MJ, *et al*. Relations of stroke volume and cardiac output to body composition: the strong heart study. *Circulation* 2001; **103**: 820–5.
19. Stelfox HT, Ahmed SB, Ribeiro RA, *et al*. Hemodynamic monitoring in obese patients: the impact of body mass index on cardiac output and stroke volume. *Crit Care Med* 2006; **34**: 1243–6.
20. Lesser GT, Deutsch S. Measurement of adipose tissue blood flow and perfusion in man by uptake of 85Kr. *J Appl Physiol* 1967; **23**: 621–30.
21. Messerli FH, Ventura HO, Reisin E, *et al*. Borderline hypertension and obesity: two prehypertensive states with elevated cardiac output. *Circulation* 1982; **66**: 55–60.
22. Ferraro S, Perrone-Filardi P, Desiderio A, *et al*. Left ventricular systolic and diastolic function in severe obesity: a radionuclide study. *Cardiology* 1996; **87**: 347–53.
23. Messerli FH, Christie B, DeCarvalho JG, *et al*. Obesity and essential hypertension. Hemodynamics, intravascular volume, sodium excretion, and plasma renin activity. *Arch Int Med* 1981; **141**: 81–5.
24. Wong C, Marwick TH. Obesity cardiomyopathy: diagnosis and therapeutic implications. *Nat Clin Pract Cardiovasc Med* 2007; **4**: 480–90.
25. Lorell BH, Carabello BA. Left ventricular hypertrophy: pathogenesis, detection, and prognosis. *Circulation* 2000; **102**: 470–9.
26. Archan S, Toller W. Levosimendan: current status and future prospects. *Curr Opin Anaesthesiol* 2008; **21**: 78–84.
27. Bella JN, Devereux RB, Roman MJ, *et al*. Relations of left ventricular mass to fat-free mass and adipose body mass: the strong heart study. The Strong Heart Study Investigators. *Circulation* 1998; **98**: 2538–44.
28. Avelar E, Cloward TV, Walker JM, *et al*. Left ventricular hypertrophy in severe obesity: interactions among blood pressure, nocturnal hypoxemia, and body mass. *Hypertension* 2007; **49**: 34–9.
29. de Simone G, Devereux RB, Roman MJ, *et al*. Relation of obesity and gender to left ventricular hypertrophy in normotensive and hypertensive adults. *Hypertension* 1994; **23**: 600–6.
30. Haque AK, Gadre S, Taylor J, *et al*. Pulmonary and cardiovascular complications of obesity: an autopsy study of 76 obese individuals. *Arch Pathol Lab Med* 2008; **132**: 1397–404.
31. Lavie CJ, Messerli FH. Cardiovascular adaptation to obesity and hypertension. *Chest* 1986; **90**: 275–9.
32. Woodiwiss AJ, Libhaber CD, Majane OH, *et al*. Obesity promotes left ventricular concentric rather than eccentric geometric remodeling and hypertrophy independent of blood pressure. *Am J Hypertens* 2008; **21**: 1144–51.
33. de Simone G. Concentric or eccentric hypertrophy: how clinically relevant is the difference? *Hypertension* 2004; **43**: 714–5.
34. Lavie CJ, Milani RV, Ventura HO, *et al*. Disparate effects of left ventricular geometry and obesity on mortality

in patients with preserved left ventricular ejection fraction. *Am J Cardiol* 2007; **100**: 1460–4.

35. Juric D, Wojciechowski P, Das K, *et al*. Prevention of concentric hypertrophy and diastolic impairment in aortic-banded rats treated with rosveratrol. *Am J Physiol Heart Circ Physiol* 2007; **292**: H2138–43.
36. Paulus WJ, Tschope C, Sanderson JE, *et al*. How to diagnose diastolic heart failure: a concensus statement on the diagnosis of heart failure with normal left ventricular ejection fraction by the Heart Failure and Echocardiography Associations of the European Society of Cardiology. *Eur Heart J* 2007; **28**: 2539–50.
37. Peterson LR. Obesity and insulin resistance: effects on cardiac structure, function, and substrate metabolism. *Curr Hypertens Rep* 2006; **8**: 451–6.
38. Pirracchio R, Cholley B, De Hert S, *et al*. Diastolic heart failure in anesthesia and intensive care. *Br J Anaesth* 2007; **98**: 707–21.
39. Aurigemma GP, Zile MR, Gaasch WH. Contractile behavior of the left ventricle in diastolic heart failure: with emphasis on regional systolic function. *Circulation* 2006; **113**: 296–304.
40. Wong CY, O'Moore Sullivan T, Leano R, *et al*. Association of subclinical right ventricular dysfunction with obesity. *J Am Coll Cardiol* 2006; **47**: 611–6.
41. Maniscalco M, Arciello A, Zedda A, *et al*. Right ventricular performance in severe obesity. Effect of weight loss. *Eur J Clin Invest* 2007; **37**: 270–5.
42. Greyson CR. Pathophysiology of right ventricular failure. *Crit Care Med* 2008; **36**(1 Suppl): S57–65.
43. Boutet K, Montani D, Jais X, *et al*. Therapeutic advances in pulmonary arterial hypertension. *Ther Adv Respir Dis* 2008; **2**: 249–65.
44. Kenchaiah S, Evans S, Levy D, *et al*. Obesity and the risk of heart failure. *N Engl J Med* 2002; **347**: 305–13.
45. Oreopoulos A, Padwal R, Kalantar-Zadeh K, *et al*. Body mass index and mortality in heart failure: a meta-analysis. *Am Heart J* 2008; **156**: 13–22.
46. Gustafsson F, Kragelund CB, Torp-Pedersen C, *et al*. Effect of obesity and being overweight on long-term mortality in congestive heart failure: influence of left ventricular systolic function. *Eur Heart J* 2005; **26**: 58–64.
47. Dublin S, French B, Glazer NL, *et al*. Risk of new-onset atrial fibrillation in relation to body mass index. *Arch Intern Med* 2006; **166**: 2322–8.
48. Wang TJ, Parise H, Levy D, *et al*. Obesity and the risk of new-onset atrial fibrillation. *JAMA* 2004; **292**: 2471–5.
49. Gami AS, Hodge DO, Herges RM, *et al*. Obstructive sleep apnea, obesity, and the risk of incidental atrial fibrillation. *J Am Coll Cardiol* 2007; **49**: 565–71.
50. Tsang TS, Barnes ME, Miyasaka Y, *et al*. Obesity as a risk factor for the progression of paroxysmal to permanent atrial fibrillation: a longitudinal cohort study of 21 years. *Eur Heart J* 2008; **29**: 2227–33.
51. Roy D, Talajic M, Nattel S, *et al*. Rhythm control versus rate control for atrial fibrillation and heart failure. *N Engl J Med* 2008; **358**: 2667–77.
52. Somers VK, White DP, Amin R, *et al*. Sleep apnea and cardiovascular disease. *Circulation* 2008; **118**: 1080–111.
53. Bradley TD, Floras JS. Obstructive sleep apnea and its cardiovascular consequences. *Lancet* 2009; **373**: 82–93.
54. Valencia-Flores M, Orea A, Castano VA, *et al*. Prevalence of sleep apnea and electrocardiographic disturbances in morbidly obese patients. *Obes Res* 2000; **8**: 262–9.
55. Papaioannou A, Michaloudis D, Fraidakis O, *et al*. Effects of weight loss on QT interval in morbidly obese patients. *Obes Surg* 2003; **13**: 869–73.
56. Artz M, Bradley TD. Treatment of sleep apnea in heart failure. *Am J Respir Crit Care Med* 2006; **173**: 1300–8.
57. Ikonomidis I, Mazarakis A, Papadopoulos C, *et al*. Weight loss after bariatric surgery improves aortic elastic properties and left ventricular function in individuals with morbid obesity: a 3-year follow-up study. *J Hypertens* 2007; **25**: 439–47.
58. Good D, Morse SA, Ventura HO, *et al*. Obesity, hypertension, and the heart. *J Cardiometab Syndr* 2008; **3**: 168–72.
59. Gonzaga CC, Calhoun DA. Resistant hypertension and hyperaldosteronism. *Curr Hypertens Rep* 2008; **10**: 496–503.
60. Witteles RM, Fowler MB. Insulin-resistant cardiomyopathy clinical evidence, mechanisms, and treatment options. *J Am Coll Cardiol* 2008; **51**: 93–102.
61. Ioannidis I. The road from obesity to type 2 diabetes. *Angiology* 2008; **59**(2 Suppl): 39S–43S.
62. Peterson LR, Herrero P, Schechtman KB *et al*. Effect of obesity and insulin resistance on myocardial substrate metabolism and efficiency in young women. *Circulation* 2004; **109**: 2191–6.
63. Grundy SM. Obesity, metabolic syndrome, and coronary atherosclerosis. *Circulation* 2002; **105**: 2696–8.
64. Jensen MK, Chuive SE, Rimm EB, *et al*. Obesity, behavioral lifestyle factors, and risk of acute coronary events. *Circulation* 2008; **117**: 3062–9.
65. Fraley MA, Birchem JA, Senkottaiyan N, *et al*. Obesity and the electrocardiogram. *Obes Rev* 2005; **6**: 275–81.
66. Ashrafian H, le Roux CW, Darzi A, *et al*. Effects of bariatric surgery on cardiovascular function. *Circulation* 2008; **118**: 2091–102.
67. Ristow B, Rabkin J, Haeusslein E. Improvement in dilated cardiomyopathy after bariatric surgery. *J Card Fail* 2008; **14**: 198–202.

68. Di Bello V, Santini F, Di Cori A, *et al*. Effects of bariatric surgery on early myocardial alterations in adult severely obese subjects. *Cardiology* 2008; **109**: 241–8.
69. Muscelli E, Camastra S, Catalano C, *et al*. Metabolic and cardiovascular assessment in moderate obesity: effect of weight loss. *J Clin Endocrinol Metab* 1997; **82**: 2937–43.
70. Sugerman HJ, Baron PL, Fairman RP, *et al*. Hemodynamic dysfunction in obesity hypoventilation syndrome and the effects of treatment with surgically induced weight loss. *Ann Surg* 1988; **207**: 604–13.
71. Willens HJ, Chakko SC, Byers P, *et al*. Effects of weight loss after gastric bypass on right and left ventricular function assessed by tissue Doppler imaging. *Am J Cardiol* 2005; **95**: 1521–4.

Chapter 2

Pulmonary physiology and sleep disordered breathing

Roman Schumann and Stephanie B. Jones

2.1 Introduction

Complex changes to pulmonary function and physiology occur with increasing obesity. Depending on the degree of obesity present and the distribution of adipose tissue, these changes lead to alterations in pulmonary gas exchange, and, ultimately, contribute to cardiovascular changes and morbidity. Obesity is also linked to sleep disordered breathing syndromes, most commonly obstructive sleep apnea (OSA) and obesity hypoventilation syndrome (OHS). This chapter summarizes current knowledge about changes in pulmonary physiology associated with obesity and describes the pathophysiology of OSA and OHS.

2.2 Changes in pulmonary function

Obesity may affect pulmonary function in a number of ways [1]. Chest wall, abdominal cavity and intrathoracic accumulation of excess adipose tissue results in a restrictive pulmonary physiology with decreased compliance and diminished lung volumes. Cephalad displacement of the diaphragm from intra-abdominal fat and increased pulmonary blood volume further reduces lung volumes [2]. At rest, tidal volume, normalized to total body weight (TBW) or lean body weight (LBW), is 50% and 20% reduced, respectively, when compared to normal weight patients. Resting respiratory rate in the severely obese is 40% higher than for normal weight individuals [3]. Even more modest increases in BMI affect the functional residual capacity (FRC) and the expiratory reserve volume (ERV). The FRC and the ERV of a person with a BMI of 30 kg m^{-2} are reduced by 25% and 53% compared to an individual with a BMI of 20 kg m^{-2} [4]. A 1% decrease in FRC and ERV can be expected for each unit of BMI increase above 30. The reduction in the forced expiratory volume in 1 s (FEV_1) is inversely proportional to BMI, a significant finding because it is an independent predictor of all-cause mortality [1]. Because the forced vital capacity (FVC) also declines, the FEV_1 to FVC ratio often remains unchanged [5]. Total lung capacity (TLC), vital capacity and residual volume can be expected to be reduced by 0.5% for each unit of BMI increase [4]. In anesthetized supine patients, FRC and lung compliance are exponentially reduced with an increasing BMI. Furthermore, respiratory system (lung and chest wall) resistance increases with rising BMI, mainly due to the resistance of the lung component [6] (Figure 2.1).

Recently the effects of adipose tissue distribution and the influence of gender on pulmonary physiologic changes have been investigated. Weight gain appears to affect pulmonary function in men more than in women, most likely due to a more central fat distribution with diaphragmatic impairment in men [1]. Central obesity causes greater decline in TLC, FVC and FEV_1 compared to peripheral obesity [5]. Therefore waist circumference and waist-to-hip ratio as measures of central or abdominal adipose tissue distribution may be more useful to estimate the effect of obesity on pulmonary function than BMI [1, 2].

2.2.1 Respiratory physiologic changes

The alterations in mechanical pulmonary function are amplified by several physiologic changes of obesity. The increased LBW and excess adipose tissue increase oxygen consumption and carbon dioxide production to satisfy metabolic requirements even at rest, resulting in increased minute ventilation. Central adipose tissue especially appears to be metabolically active, producing cytokines that contribute to a low-grade inflammatory state in obesity. These cytokines include tumor necrosis factor alpha, interleukin-6, leptin, adiponectin, and others, and are possibly associated with the reduced pulmonary function, and may contribute to airway reactivity and cardiovascular morbidity [1, 2].

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

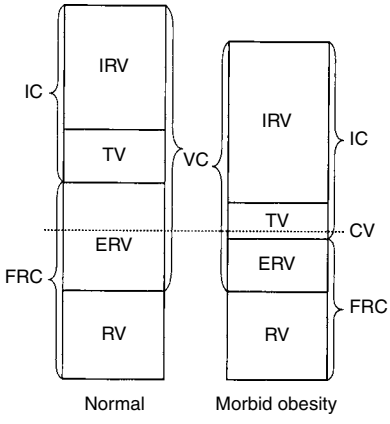

Figure 2.1 Comparative lung volumes and capacities between lean and obese subjects. IRV, inspiratory reserve volume; TV, tidal volume; ERV, expiratory reserve volume; RV, residual volume; IC, inspiratory capacity; FRC, functional residual capacity; CV, closing volume. CV is the volume above RV during expiration at which airway closure occurs. If RV exceeds ERV as in severe obesity, airways close during the normal TV cycle resulting in hypoxemia. The situation is worse in the supine position, during anesthesia and post-operatively. From: Campos MA, Wanner A. Lung physiology. In: Alvarez F, Brodsky J, Alpert M, Cowan G, eds. *Morbid Obesity: Peri-operative Management*. Cambridge, Cambridge University Press. 2004; 45–57. Used with permission.

The increased minute volume and the restrictive pulmonary pathophysiology result in a significant increased work of breathing [5]. In simple obesity (also called "uncomplicated" obesity without co-morbidity or sleep disordered breathing) work of breathing is increased by 70%, and the energy or oxygen cost of breathing (oxygen consumed by respiratory muscles per liter of ventilation) rises four-fold. Further weight gain may augment this work of breathing up to 280% of normal, and lead to a ten-fold increase in the energy cost of breathing [3]. Respiratory muscle dysfunction is possibly due to cytokines and fatty infiltration [1, 2]. Muscle inefficiency and decreased muscle endurance, as indicated by decreases in maximal voluntary ventilation, make it more difficult for the respiratory system to satisfy the increased ventilatory demand of obesity [5, 7].

2.2.2 Pulmonary gas exchange

The above mentioned mechanical changes in pulmonary function due to obesity increasingly affect the pulmonary gas exchange as body weight increases, especially above a BMI of 40 kg m^{-2} [8]. However, BMI alone may be less important than the distribution of the adipose tissue. Waist circumference or, even more, waist-to-hip ratio, may be better markers for change in pulmonary gas exchange. This also explains the gender differences found for arterial pressure of oxygen (PaO_2), the alveolar-to-arterial oxygen partial pressure difference ($AaDO_2$), and the arterial oxyhemoglobin saturation (%SaO_2). Despite the same BMI, gas exchange is worse in men than women. Women generally have a lower waist-to-hip ratio [8]. Low lung volumes, particularly ERV and FRC, decreased chest wall compliance, and raised intra-abdominal pressure from visceral adipose tissue accumulation elevating the diaphragm lead to airway closure during tidal breathing, atelectasis and subsequent ventilation-perfusion mismatch and, possibly, shunt [3, 5, 8]. In seated, severely obese individuals the lower portions of the lungs are relatively over-perfused and under-ventilated. The ventilation–perfusion inequality is further exacerbated as FRC declines in the supine position.

In one study of the severely obese (BMI > 40 kg m^{-2}) patients at rest, the $AaDO_2$ was 23 mmHg or approximately four times higher than expected for normal weight individuals, and the PaO_2 was 81 mmHg or 83% of the predicted value. The PaO_2 increases by 1 mmHg, and the $AaDO_2$ decreases by 1 mmHg for every 5–6 kg of weight reduction [8].

2.2.3 Obesity and asthma

Approximately 5% of the general population has a diagnosis of asthma and the prevalence of this condition has been increasing annually [2]. Symptoms such as wheezing, dyspnea, and poor exercise tolerance, which are suggestive of a diagnosis of asthma, are often present in severely obese patients [1]. It is currently under investigation as to whether severe obesity and asthma are causally linked. Asthma-like symptoms in the obese patient may be explained by low lung volumes, narrower airways, increased airway resistance, increased work of breathing, and deconditioning [1, 9]. Large epidemiologic studies showing frequent wheezing and dyspnea in obese (BMI > 35 kg m^{-2}) patients did not find increased levels of atopy, airway hyper-responsiveness and airway obstruction that would confirm a diagnosis of asthma in the obese patient population [9]. These findings would suggest that peri-operative use of bronchodilators in some patients with a presumed diagnosis of asthma may be less effective than expected and desired.

On the other hand, data from prospective epidemiologic studies showed a 50% increase in the incidence of asthma in self-reported overweight and obese individuals [1]. Both asthma and obesity are low-grade

systemic inflammatory conditions possibly implying a common etiology between the two [2, 10]. The increased levels of the proinflammatory satiety hormone leptin, which is elevated in obesity, along with inflammatory mediators that include interleukin-6, tumor necrosis factor, and C-reactive protein, may contribute to airway hyper-responsiveness [2, 10].

Co-morbidities associated with severe obesity may trigger or worsen airway reactivity and asthma. Such conditions include gastroesophageal reflux disease and chronic aspiration [2, 10], hypertension with increased levels of the bronchoconstrictor endothelin, dyslipidemia and type 2 diabetes [10]. Treatment of these co-morbidities may improve asthma and its symptoms in this population. Weight loss improves asthma outcomes, supporting a link between asthma and obesity [10]. Surgical weight loss in severely obese individuals has been shown to improve asthma severity scores by 90% on average, and weight loss to a BMI of 30 kg m^{-2} may resolve asthma symptoms completely [2].

2.3 Sleep disordered breathing

Sleep disordered breathing syndromes include OSA and OHS. Obesity is a major risk/causative factor for both these entities.

2.3.1 Obstructive sleep apnea

Approximately 2–4% of the adult middle-aged general population are affected by OSA [11], and 50–70% of those with OSA are obese [1]. The prevalence of OSA among obese individuals is estimated to be 40% [1], and among patients presenting for weight loss surgery, more than 70% may have OSA [12, 13]. Obstructive sleep apnea remains a frequently under-diagnosed condition in the obese population [2], but its presence, especially when unrecognized, may result in adverse peri-operative outcomes, including death. Poor outcomes are often related to difficulties with peri-operative airway management and pain treatment [11].

2.3.2 Definition of obstructive sleep apnea and polysomnography

Based on clinical and electroencephalographic criteria normal sleep includes one stage of rapid eye movement (REM) sleep and one to four stages of non-REM (NREM) sleep, the higher number indicating the deeper sleep phase. Rapid eye movement and stages 3 and 4 of NREM sleep represent restorative sleep, and a typical night's sleep contains four to six cycles of NREM sleep, each followed by REM sleep [14]. Repetitive collapse of the upper airway during REM and stages 3 and 4 of NREM sleep characterizes OSA. This results in complete (apnea) or near complete (hypopnea) cessation of airflow. An apnea is defined as a lack of airflow lasting at least 10 s, and a hypopnea is a decrease of ≥ 50% in airflow or ≤ 50% for at least 10 s with either arousal from sleep or an oxygen desaturation of ≥ 3% or 4% [3, 11]. Continued and increasing respiratory effort categorizes these events as obstructive, whereas in central sleep apnea there is no breathing effort, and mixed OSA begins as central apnea or hypopnea and ends with an obstructive event [3, 11].

Polysomnography (PSG) is the gold standard for diagnosis and assessment of severity for OSA. Although ambulatory applications are being tested, PSG usually requires an overnight stay in a sleep center. Complex recordings during PSG include the electroencephalogram, electrooculogram, submental electromyogram, ECG, rib-cage and abdominal excursion, oro-nasal airflow measurements, oxyhemoglobin saturation, and non-invasive blood pressure (Figure 2.2).

The results of the PSG are analyzed for sleep architecture and quality, arousals, breathing and airflow patterns, activity of the pharyngeal dilator musculature, respiratory effort, oxygen saturation, body positioning, and cardiac dysrhythmias during sleep [3, 11]. Results are often summarized using indices for OSA severity. The apnea index (AI) is the number of apneas per hour of total sleep time, and the hypopnea index (HI) reports the occurrence of hypopneas per hour of total sleep time. Their sum is the apnea/hypopnea index or AHI [11]. The arousal index quantifies the arousals per hour of total sleep, and the combination of arousal index and AHI is reported as the respiratory disturbance index [14]. Further analyses include the relative amounts of REM and non-REM sleep as well as the oxygen desaturation index and other variables. Arousals and sleep fragmentation up to 100 times per hour, large negative intrathoracic pressure swings (up to 120 mmHg), episodic elevations in blood pressure (often to 250/150 mmHg) and transient hypoxemia and hypercapnia have been observed in severe cases [15].

In normal sleep some degree of repetitive airway obstruction is considered normal, particularly during REM sleep when the pharyngeal musculature enters a stage of relaxation. A commonly accepted threshold that distinguishes normal sleep from a diagnosis of OSA is an AHI of 5, sometimes in combination with the presence of clinical symptoms of OSA [11, 15].

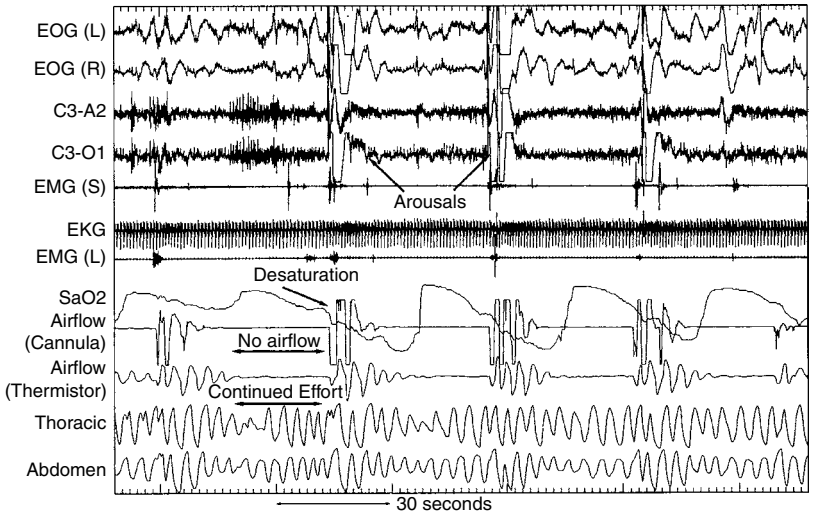

Figure 2.2 Polysomnographic tracings of obstructive sleep apnea. Channels recorded were electrooculogram (EOG) from both eyes; electromyogram (EMG) of chin (S) and leg (L); electroencephalogram (EEG) from standard locations C3-A2 and C3-O1; electrocardiogram (ECG); oxygen saturation (SaO2); airflow (cannula and thermistor); and respiratory (thoracic and abdomen). From Ref. [11], with permission.

The American Society of Anesthesiologists (ASA) published guidelines for the peri-operative management of patients with OSA, establishing a framework to guide peri-operative care at different levels of OSA severity [16]. In this consensus guideline, it is recommended that the severity of OSA after a sleep study be classified according to the reports' narrative as mild, moderate, or severe. If the PSG study does not provide such commentary, the ASA regards an AHI of 0–5 as normal, 6–20 as mild, 21–40 as moderate and > 40 as severe OSA.

2.3.3 Pathophysiology of obstructive sleep apnea in obesity

The pathophysiology of obstructive sleep apnea is very complex and can include the following factors: a narrow upper airway, a predisposition for upper airway collapsibility, decreased neuromuscular control of the upper airway musculature, advanced age, and gender (men > women) [15]. Obesity contributes to some of these predisposing factors, and an inverse relationship between obesity and pharyngeal area exists [14]. A BMI greater than 35 kg m^{-2}, and, probably more importantly, abdominal adipose tissue distribution or increased waist-to-hip ratio, a neck circumference of > 17 inches or 41 cm in men and > 16 inches or 39 cm in women, and a reduced retropharyngeal space are risk factors and determinants of OSA [1, 3, 16]. In obese individuals with OSA, increased soft tissue deposition in the pharyngeal region and tongue contributes to a decreased upper airway size [1, 3]. The pharyngeal geometry often changes from a transversely elliptical configuration to a more antero-posterior alignment in OSA, which reduces the effectiveness of upper airway muscle tension and contraction that keep the upper airway open. A reported increased thickness of the lateral pharyngeal wall in OSA patients further contributes to these changes [3, 14]. The decrease in lung volumes, especially in central obesity, leads to a reduction in longitudinal and caudal traction on the trachea and pharynx, further increasing upper airway collapsibility and resistance [3, 15].

The part of the upper airway that is not supported by bony or cartilaginous structures consists of the nasopharynx, the oro- or retroglossal pharynx, and the hypo- or retroepiglottic pharynx. The patency of these three segments during inspiration while asleep depends on the activity and contraction of the pharyngeal dilator muscles, which include the tensor palatini, the genioglossus, and the hyoid bone muscles [14]. During sleep, and particularly REM sleep, upper airway neuromuscular activity and pharyngeal muscle tone decrease: this may be more pronounced in patients with OSA [1, 17], and lead to airway obstruction in predisposed patients. The synchronization of upper airway and respiratory muscle activation that tenses the upper airway soft tissues prior to inspiratory activity is disrupted in OSA patients [18]. The genioglossus muscle, important for upper airway patency and preventing the tongue from falling posteriorly, is relaxed during REM sleep in OSA patients [19]. Upper airway resistance may double during NREM sleep compared to the awake state. It increases further

during REM sleep, when most of the pharyngeal dilator muscle relaxation occurs. Diaphragmatic contraction produces sub-atmospheric pharyngeal pressure, leading to upper airway collapse, most often involving the nasopharynx and most importantly the compliant lateral pharyngeal walls [14].

Increasing hypoxemia and hypercapnia during apneic/hypopneic events lead to a progressive ventilatory effort that terminates in an arousal that restores pharyngeal dilator muscle activity. Ultimately, repetitive sympathetic nervous system activation triggers a cascade of OSA and obesity associated cardiovascular and metabolic co-morbid conditions [17]. During apneic events, bradycardia, sinus pauses, ventricular dysrhythmias, and second-degree heart block occur in nearly 50% of OSA patients [14]. These changes increase in frequency when the arterial oxygen saturation is less than 60%. Intermittent nocturnal sympathetic activation with systemic hypertension and recurrent hypoxic pulmonary vasoconstriction with pulmonary hypertension may explain an incidence of up to 31% and 71% of right and left ventricular hypertrophy in OSA patients. These cardiovascular changes increase the myocardial infarction and stroke rate in this population and result in a cumulative 8-year mortality of 37% in patients with untreated moderate OSA versus 4% for mild OSA patients [14].

Independent of BMI and gender, advanced age has been identified to be associated with pharyngeal airway collapsibility during sleep [20].

Some evidence suggests that the increased levels of the hormone leptin found in obesity also impairs the response to apnea related hypercapnia and interferes with the arousal response [15]. Leptin therefore may play a role in the development of OHS.

Endothelial dysfunction may be independently induced by OSA from oxidative stress secondary to intermittent hypoxia and reperfusion as well as high levels of inflammatory cytokines [15]. These complex humoral changes in addition to sympathetic activation may at least in part explain the strong correlation between OSA and atherosclerotic cardiovascular diseases and metabolic derangements. Co-morbidities other than arterial hypertension associated with OSA include coronary artery disease, cerebrovascular disease and stroke, congestive heart failure, cardiac dysrhythmias, and diabetes mellitus [17]. Obstructive sleep apnea is an independent risk factor for the development of the metabolic syndrome, which includes impaired glucose tolerance, insulin resistance, and dyslipidemia [21].

2.3.4 Clinical symptoms and diagnosis of obstructive sleep apnea

Symptoms that also assist in identifying patients at risk for OSA include frequent and often disruptive snoring, observed respiratory pauses during sleep, observed arousals, gasping, and nocturnal choking. As a consequence of sleep fragmentation and deprivation, the sleep quality is unrefreshing and non-restorative [15]. This results in daytime sleepiness and somnolence, fatigue, irritability, morning headaches, personality changes, depression, and sometimes cognitive impairment and visual in-coordination [3, 11, 15]. In patients with OSA, poor visual motor coordination and sleepiness are the presumed causes for a seven-fold increased rate of automobile accidents and increased work related accidents compared to the general population [3, 14].

A clinical diagnosis of OSA is suggested based on symptoms and a history described above, in combination with physical predisposing factors. In addition to BMI, adipose tissue distribution, and neck circumference, these factors include craniofacial abnormalities, anatomic nasal obstruction, and large tonsils. Further detailed consideration of the latter three is beyond the scope of this review.

Questionnaires and checklists have been developed with a moderate to high sensitivity for OSA screening, and the ASA checklist as well as the STOP questionnaire (mnemonic for *s*noring, *t*iredness, *o*bserved you stop breathing, blood *p*ressure), both described elsewhere [16, 22], identify patients likely to develop postoperative complications [16, 22]. However, the PSG remains the standard for diagnosis and assessment of the severity of OSA.

2.3.5 Treatment of obstructive sleep apnea

The treatment options for sleep apnea can be divided into conservative measures, medical therapies, and surgical interventions. Conservative treatment focuses on weight loss, avoidance of centrally acting ventilatory depressant agents including alcohol, and management of other underlying medical conditions such as nasal congestion, hypothyroidism, and acromegaly. Medical therapies include the use of continuous positive airway pressure (CPAP) and bi-level positive airway pressure (BIPAP), use of oral appliances for mandibular advancement, medications, and nocturnal oxygen. Medications may be used to decrease REM sleep and

improve upper airway muscle tone (fluoxetine or tricyclic antidepressants), or increase resting ventilation and ventilatory chemosensitivity to hypercapnia. A multitude of surgical strategies have been developed, some of which target correction of selected causative craniofacial abnormalities. Procedures include uvulopalatopharyngoplasty, adenotonsillectomy, radiofrequency volumetric tissue reduction, maxillofacial procedures, tongue reduction, tracheostomy, and weight-loss surgery [3, 23].

Continuous positive airway pressure is the cornerstone of medical OSA therapy for severely obese patients. It can be administered by nasal mask or prongs or an oro-nasal mask and is recommended for patients with an AI > 20 or symptomatic patients with an AHI > 10 according to the American Academy of Sleep Medicine guidelines [23]. Continuous positive airway pressure provides a pneumatic stent that opens the upper airway and maintains its patency when upper airway dilator muscle activity decreases during sleep [3]. For patients requiring high levels of CPAP or those with chronic obstructive pulmonary disease, the administration of BIPAP may be more comfortable. Bi-level positive airway pressure allows for independent adjustment of inspiratory and expiratory positive airway pressure as opposed to a fixed single setting for CPAP [3, 23]. In addition, BIPAP systems may allow non-invasive ventilation with a back-up ventilatory rate, as well as flow sensitivity. The risk of barotrauma and hypercapnia is reduced with BIPAP. The appropriate level of CPAP is typically determined during a sleep study, but auto-titrating devices are also available that determine and adjust to the optimal setting in a home environment [3]. Positive airway pressure treatment has been shown to improve and alleviate all effects of OSA, including elimination of excessive daytime sleepiness, reduction of systemic and pulmonary hypertension, improvement of neurocognitive function and quality of life, and reduction of nocturnal hypoxemia and hypercapnia, and daytime hypercapnia [3, 23]. Between 72% and 91% of patients who have a CPAP prescription consider CPAP an acceptable treatment [23]. However, many patients cannot tolerate the CPAP appliance equipment for a variety of reasons and non-compliance may be as high as 50% [3, 23]. Continuous positive airway pressure side effects, which reduce compliance with use, include chest-wall discomfort, claustrophobia, xerostomia, nasal congestion, and headaches. In addition the equipment may be noisy and bulky.

2.3.6 Physiologic benefits of pre-operative continuous positive airway pressure/ bi-level positive airway pressure

Patients with OSA presenting for elective surgery can derive significant improvements in their physiologic status from pre-operative CPAP/BIPAP therapy. Tongue volume decreases and pharyngeal space enlarges following 4–6 weeks of CPAP, potentially simplifying airway management and patient safety. Four weeks of CPAP in OSA patients with congestive heart failure results in a 35% relative increase in ejection fraction and a decrease in heart rate and blood pressure [24, 25]. An abnormal ventilatory drive in obese hypercapneic patients can be corrected by two weeks of effective CPAP administration [24]. Morning hypertension and cardiovascular risk were reduced after 8 weeks of effective CPAP therapy (mask use ≥ 4 hours per night) in patients with severe OSA and metabolic syndrome [26]. Several small studies indicate improvement of pulmonary hypertension in OSA patients using CPAP for 3–6 months [25]. With emerging data increasingly suggesting such physiologic improvements in OSA patients, pre-operative CPAP treatment should be seriously considered. However, identification of optimal timing and endpoints of peri-operative CPAP application is still nascent.

2.3.7 Obstructive sleep apnea physiology in the peri-operative period

In addition to challenging airway management in OSA patients at anesthetic induction and emergence as well as peri-operatively in general, an understanding of post-operative sleep physiology and pharmacodynamic implications of patient management are also important. REM and NREM sleep stages 3 and 4, which are the restorative phases of normal sleep, are often suppressed post-operatively. This disturbance in sleep architecture is most severe during the first 2–3 post-operative days when high levels of pain are responsible for increased analgesic requirements. Deep REM sleep then often accelerates in a REM rebound over the next 3 days [14].

Centrally depressant medications decrease the ventilatory responsiveness to hypoxemia and hypercapnia in all patients, but also decrease the pharyngeal dilator muscle tone and activity in obese OSA patients. Anesthetic medications associated with pharyngeal collapse include opioids, benzodiazepines, nitrous

oxide, thiopental, propofol and small doses of neuromuscular blocking agents [14].

These post-operative sleep architecture changes in combination with pain medication requirement increase the risk for prolonged sleep apnea episodes with decreased arousal responses in OSA patients for approximately 1 week after surgery. Initially following surgery, loss of pharyngeal dilator tone and reduced responsiveness to hypoxemia and hypercapnia with subsequent life-threatening apnea may occur from drug-induced sleep including the use of opioids. Progressing through this post-operative phase, REM rebound induced deep sleep apnea and residual medication needs add to the OSA patient's risk of adverse outcomes [14].

Recognition of the increased peri-operative risks for these patients resulted in the development of guidelines for the peri-operative management of patients with OSA by the ASA in 2005 [16]. Opioid-sparing anesthetic techniques including regional anesthesia [14], and post-operative multimodal analgesic regimens that include local anesthetics, non-steroidal anti-inflammatory agents, and other synergistic drugs are currently being explored and promoted to reduce the respiratory depressant effects of centrally acting agents and to improve peri-operative safety in patients with OSA [27]. Alpha-2 agonist medications, such as clonidine and dexmedetomidine, are anesthetic and opioid-sparing drugs that lack respiratory depression and have analgesic properties. Their role for peri-operative care in OSA patients is potentially promising but remains to be further elucidated [21, 27].

Expert consensus concluded that the degree of peri-operative risk for patients with OSA depends on the severity of the OSA and the type of surgery [16]. Risk is further influenced by related co-morbidities, but it is uncertain to what degree [21]. Beyond the ASA consensus-based guidelines for peri-operative management of OSA patients, it remains to be determined by evidence-based research if OSA screening and the suggested implementation of peri-operative OSA management strategies can truly reduce peri-operative risk [21].

2.4 Obesity hypoventilation syndrome

Obesity hypoventilation syndrome is defined as the combination of sleep disordered breathing with awake chronic hypercapnia ($PaCO_2 \geq 45$ mm Hg) and obesity (BMI of ≥ 30 kg m^{-2}) [2, 15, 28]. The obesity in OHS can be extreme, and in 1956 the term "Pickwickian syndrome" was applied as a description for OHS because these patients often resemble a character from Charles Dickens' *The Pickwick Papers* [5]. The sleep disordered breathing in OHS consists of OSA in nearly 90% of patients. In the remaining 10% of OHS patients, the AHI < 5, and a nocturnal rise in $PaCO_2$ associated with significant hypoxemia, occurs in the absence of obstructive hypopneas or apneas [28]. The exact pathophysiology of OHS is unclear, but in addition to the many etiologic similarities with OSA, there seems to be a component of diminished ventilatory drive despite an elevated $PaCO_2$ [2]. One explanation currently under investigation is a possible resistance to increased leptin levels in OHS patients, depressing the ventilatory drive and blunting the central chemo-responsiveness to elevated $PaCO_2$ [2, 15, 28].

Obesity hypoventilation syndrome is a diagnosis of exclusion and requires the absence of other reasons for chronic hypoventilation such as chronic lung or neuromuscular disease [15, 28]. The prevalence of OHS in the general population is unknown and, as in OSA, the condition is frequently under diagnosed [2, 28]. The prevalence of OHS among OSA patients ranges between 10% and 20% and is higher in patients with a BMI ≥ 40 kg m^{-2}. In obese hospitalized patients (BMI ≥ 35 kg m^{-2}), OHS has a prevalence of more than 30% [15, 28], and is more common in men than women [28]. Obesity hypoventilation syndrome patients not receiving CPAP/BIPAP treatment, have an 18-month mortality of 23% and the 7-year mortality reaches 46%. All-cause mortality is reduced to 3% following 18 months of positive airway pressure treatment, and 5-year survival reaches 88% with long-term treatment [15].

Clinically, OHS patients are often extremely obese and present with most of the symptoms described for OSA patients. However, compared to matched OSA patients (BMI, age, and lung function) individuals with OHS have lower daytime oxygen saturations, a lower quality of life, increased daytime somnolence, and greater medical resource utilization [28]. The severity of pulmonary hypertension is greater in OHS than OSA patients and more frequent (50% vs. 15%). Serum bicarbonate levels are elevated in OHS to compensate for chronic respiratory acidosis, and it can be used together with the severity of OSA as a predictor of OHS in MO patients [28]. Erythrocytosis and electrocardiographic evidence of right heart strain and hypertrophy are not infrequent.

Although the optimal treatment of OHS patients has not been clarified, in addition to weight loss the first-line treatment for OHS consists of CPAP or BIPAP [15, 28]. As in OSA patients, positive pressure therapy will stent the upper airway open, reduce the work of breathing and improve tidal volume and gas exchange [15]. Supplemental oxygen may be needed for approximately 50% of OHS patients [28], but oxygen therapy alone can increase the AHI, hypoventilation, and $PaCO_2$ levels [15]. In contrast to OSA patients who may use home auto-titration, positive airway pressure and oxygen titration for OHS is best accomplished in a supervised (e.g., sleep laboratory) setting, because otherwise hypoventilation and hypoxemia may not be recognized [28]. The improvement in daytime hypoxemia and hypercapnia is dependent on the daily dose of CPAP/BIPAP administration and an improved response to hypercapnia may begin after 2 weeks of treatment. At as early as 4 weeks of therapy the highest achievable blood gas improvement may be reached, and the minute ventilation response to hypercapnia is optimized after 6 weeks, although it does not reach normal levels [28].

Additional treatment options for OHS similar to those for OSA are available including pharmacotherapy, but these have been less well studied in this population.

The significant potential cardio-pulmonary co-morbidities present in OHS patients mandate a high index of suspicion to identify these patients preoperatively. A multidisciplinary approach to perioperative risk identification, risk stratification and risk reduction should best serve the patient with OHS and should include consideration for early post-operative positive airway pressure treatment whenever feasible.

References

1. McClean KM, Kee F, Young IS, *et al*. Obesity and the lung: 1 Epidemiology. *Thorax* 2008; **63**: 649–54.
2. Davis G, Patel JA, Gagne DJ. Pulmonary considerations in obesity and the bariatric surgical patient. *Med Clin N Am* 2007; **91**: 433–42.
3. Koenig SM. Pulmonary complications of obesity. *Am J Med Sci* 2001; **321**: 249–79.
4. Jones RL, Nzekwu M-M U. The effects of body mass index on lung volumes. *Chest* 2006; **130**: 827–33.
5. Kuchta KF. Pathophysiologic changes of obesity. *Anesthesiol Clin N Am* 2005; **23**: 421–9.
6. Pelosi P, Croci M, Ravagnan I, *et al*. The effects of body mass on lung volumes, respiratory mechanics, and gas exchange during general anesthesia. *Anesth Analg* 1998; **87**: 654–60.
7. Parameswaran K, Todd DC, Soth M. Altered respiratory physiology in obesity. *Can Respir J* 2006; **13**: 203–10.
8. Zavorsky GS, Hoffman SL. Complications of obesity. Pulmonary gas exchange in the morbidly obese. *Obes Rev* 2008; **9**: 326–39.
9. Schachter LM, Salome CM, Peat JK, *et al*. Obesity is a risk factor for asthma and wheeze but not airway hyperresponsiveness. *Thorax* 2001; **56**: 4–8.
10. Shore SA. Obesity and asthma: possible mechanisms. *J Allergy Clin Immunol* 2008; **121**: 1087–93.
11. Stierer T, Punjabi NM. Demographics and diagnosis of obstructive sleep apnea. *Anesthesiol Clin N Am* 2005; **23**: 405–20.
12. Frey WC, Pilcher J. Obstructive sleep related breathing disorders in patients evaluated for bariatric surgery. *Obes Surg* 2003; **13**: 676–83.
13. O'Keeffe T, Patterson EJ. Evidence supporting routine polysomnography before bariatric surgery. *Obes Surg* 2004; **14**: 23–6.
14. Benumof JL. Obesity, sleep apnea, the airway and anesthesia. *Curr Opin Anaesthesiol* 2004; **17**: 21–30.
15. Crummy F, Piper AJ, Naughton MT. Obesity and the lung: 2 Obesity and sleep-disordered breathing. *Thorax* 2008; **63**: 738–46.
16. Gross JB, Bachenberg KL, Benumof JL *et al*. Practice guidelines for the perioperative management of patients with obstructive sleep apnea. *Anesthesiology* 2006: **104**: 1081–93.
17. Pashayan AG, Passannante AN, Rock P. Pathophysiology of obstructive sleep apnea. *Anesthesiol Clin N Am* 2005; **23**: 431–43.
18. Tung A. The biology and genetics of obesity and obstructive sleep apnea. *Anesthesiol Clin N Am* 2005; **23**: 445–61.
19. Bell RL, Rosenbaum SH. Postoperative considerations for patients with obesity and sleep apnea. *Anesthesiol Clin N Am* 2005; **23**: 493–500.
20. Eikermann M, Jordan AS, Chamberlin NL, *et al*. The influence of aging on pharyngeal collapsibility during sleep. *Chest* 2007; **13**: 1702–9.
21. Chung SA, Yuan H, Chung F. A systemic review of obstructive sleep apnea and its implications for anesthesiologists. *Anesthesiology* 2008; **107**: 1543–63.
22. Chung F, Yegneswaran B, Liao P, *et al*. Validation of the Berlin questionnaire and the American Society of Anesthesiologists checklist as screening tools for obstructive sleep apnea in surgical patients. *Anesthesiology* 2008; **108**: 822–30.
23. Couch EM, Senior B. Nonsurgical and surgical treatments for sleep apnea. *Anesthesiol Clin N Am* 2005; **23**: 525–34.
24. Cartagena R. Preoperative evaluation of patients with obesity and obstructive sleep apnea. *Anesthesiol Clin N Am* 2005; **23**: 463–78.

25. Golbin JM, Somers VK, Caples SM. Obstructive sleep apnea, cardiovascular disease and pulmonary hypertension. *Proc Am Thorac Soc* 2008; **5**: 200–6.
26. Dorkova Z, Petrasova D, Molcanyiova A, *et al*. Effects of continuous positive airway pressure on cardiovascular risk profile in patients with severe obstructive sleep apnea and metabolic syndrome. *Chest* 2008; **134**: 686–92.
27. Schumann R, Jones SB, Cooper B, *et al*. Update on best practice recommendations for anesthetic perioperative care and pain management in weight loss surgery 2004–2007. *Obesity (Silver Spring)* 2009; **17**: 889–94.
28. Mokhlesi B, Tulaimat A. Recent advances in obesity hypoventilation syndrome. *Chest* 2007; **132**: 1322–36.

Chapter 3

Digestive and metabolic physiology of obesity

Patrick J. Neligan

3.1 Introduction

Excess energy intake results in fat accumulation in various locations in the body. Once considered inert, it now appears that adipose tissue is an active metabolic and endocrine organ. Progressive accumulation of body fat results in the development of a multisystem disease state, probably initiated by a dramatic elevation in hepatic and circulating fatty acid levels. The consequences include an escalation in the risk of cardiovascular, pulmonary, hepatic, and endocrine disease, and cancer. How does dietary fat, an essential component of homeostasis, turn from nutrient to poison? This chapter will look at several aspects of metabolic and digestive diseases associated with obesity. We will begin with a look at the pathogenesis and impact of non-alcoholic fatty liver disease (NAFLD). Then we will discuss insulin resistance (IR) and the onset of type 2 diabetes (T2D). Subsequently, we will see how each of these factors coalesces into a behemoth of risk factors, the metabolic syndrome (MetS). Finally, we will look at peri-operative risk for patients that have obesity-related metabolic disease and strategies to prevent associated peri-operative complications.

3.2 Non-alcoholic fatty liver disease

Dietary fats are ingested principally as triglycerides. The pancreas produces lipase that breaks down triglycerides into fatty acids and monoglycerides. These are, in turn, emulsified by bile salts that facilitate absorption across the bowel wall. Following absorption, fatty acids are reconstructed as triglycerides and packaged into chylomicrons and transported to the liver or to adipose tissue. Once there, lipoprotein lipase hydrolyses the triglycerides back into (non-esterified) fatty acids and glycerol and they are either stored or oxidized. The liver is the major site of fat metabolism. It processes fatty acids into very low density lipoprotein (VLDL) and low density lipoprotein (LDL). Very low density lipoprotein is the major transport system for fatty acids synthesized in the liver. Peripherally these are processed into LDLs and fatty acids by lipoprotein lipase. There is a continuous cycle of fat breakdown in adipose tissue and re-esterification in the liver. This is modulated by insulin, the major anabolic hormone of metabolism. Insulin promotes glucose and fat synthesis and storage. It does this by promoting transport of glucose into adipose tissue and hepatocytes, by activation of lipoprotein kinase, and by inhibiting the action of hormone-sensitive lipase.

Obesity is associated with a dual problem for these metabolic processes: excessive delivery of fat and carbohydrate to the liver and reduced effectiveness of insulin in regulating fat metabolism. In obesity there is, essentially, continuous energy intake: this accelerates the synthesis and storage of fatty acids. As there is a close correlation between the quantity of insulin in the portal circulation and hepatic conversion of glucose to fatty acids [1], fat accumulates in the liver (Figure 3.1). This problem is exacerbated by peripheral IR, particularly in muscle tissue. As there is a dramatic increase in the production of fatty acids and triglycerides, this also results in increased circulating fat. It is probable that fatty liver is associated with simultaneous deposition of fat around the islet cells of the pancreas, resulting in impaired cell function, and in suppression of glucose-mediated insulin secretion. The consequence is a vicious cycle of hepatic steatosis and hyperglycemia (Figure 3.2).

Fatty liver is resistant to the action of insulin, in particular in the suppression of hepatic glucose production. The result is hyperglycemia and hyperinsulinemia. This hepatic insulin resistance is associated with impaired insulin clearance. There is loss of the

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

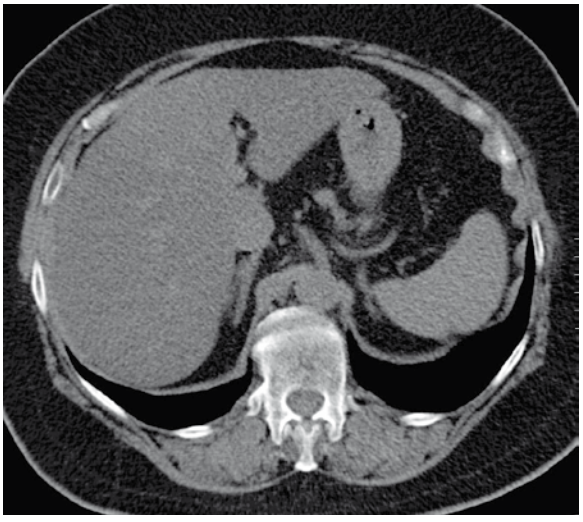

Figure 3.1 Non-alcoholic fatty liver disease on computed tomography (CT): Liver is darker than spleen on non-contrast axial image consistent with fatty infiltration.

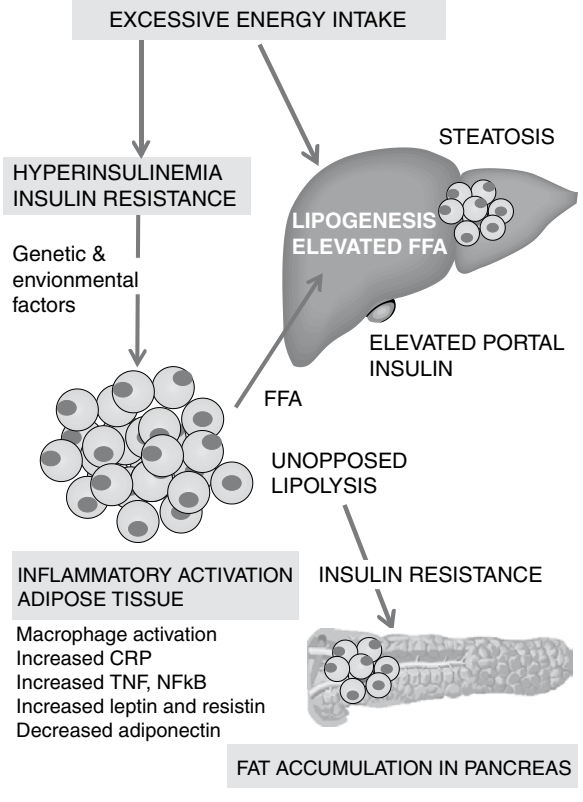

Figure 3.2 Pathogenesis of non-alcoholic fatty liver disease. CRP, C reactive protein; FFA, free fatty acids; TNF, tumor necrosis factor; NFkB: nuclear factor-kappa B.

normal phasic response of insulin to meal times resulting in fasting hyperinsulinemia. Hence endogenous insulin secretion appears to be the major promoter of hepatic steatosis. Insulin normally inhibits hepatic VLDL production. However, in hepatic steatosis there is overproduction of VLDL and hypertriglyceridemia, and depression of high density lipoprotein (HDL) levels.

Low calorie diets and exercise lower insulin secretion rates, and thiazolidinediones increase insulin sensitivity and decrease insulin secretion rates. Exogenous insulin therapy has been shown to reduce liver fat content considerably [2]. These data suggest that endogenous hyperinsulinemia is the consequence rather than the cause of hepatic steatosis [3].

During weight loss, for example following bariatric surgery, there is a tight relationship between liver volume and liver fat content. As energy intake falls, hepatic fat is mobilized before visceral and subcutaneous fat, and the liver shrinks in size. Both Petersen and Hollingsworth have demonstrated that very soon after hypocaloric feeding commences, hepatic fat content diminishes substantially [4, 5]. For example, in Petersen's study [5], an overall weight loss of 8% was associated with a 81% reduction in hepatic fat. The shrinkage in liver size makes the surgical approach to restrictive bariatric procedures less difficult.

With weight loss there is a simultaneous improvement in hepatic insulin sensitivity and a fall in blood glucose levels. The reduction in hepatic fat content is associated with increased hepatic suppression of glucose production by insulin.

3.2.1 Non-alcoholic fatty liver disease and type 2 diabetes

It is now believed that T2D is a disease characterized by hepatic steatosis as well as dysregulation of glucose metabolism. Serum alanine aminotransferase (ALT) levels correlate with liver fat content, and this has been used as a marker of the development and progress of hepatic steatosis [6]. Fatty liver appears to uniformly precede the onset and diagnosis of T2D [6]. Sattar and colleagues looked at a cohort of men who did and did not develop T2D [7]. Nine per cent of patients in the study developed T2D, and these patients had demonstrable hypertriglyceridemia and raised ALT at 2 years prior to diagnosis. There was a progressive rise in the levels of these compounds over time, reflecting worsening hepatic steatosis [7]. Shibata and colleagues have

demonstrated, in a cohort of 3189 Japanese men, that if fatty liver is excluded at baseline, the development of T2D is rare [8]. Of particular interest in Sattar and colleagues' study was the revelation that there appears to be an upward inflection point in the level of blood glucose, as opposed to the gradual increase in triglycerides and liver enzymes [7]. This is, presumably, the point where endogenous insulin fails to suppress glucose production and facilitate muscular storage. The islet cells decompensate. Why this occurs at this time is unclear: fatty liver is an essential component of the development of T2D, but not all patients with fatty livers develop pathologic hyperglycemia. Perhaps different individuals have different degrees of islet cell sensitivity to hypertriglyceridemia, and this is genetically determined. In the short term, reversal of hepatic steatosis appears to result in reversal of T2D. However, in the long term (more than 2 or 3 years), irreversible islet cell damage occurs, and diabetes persists.

Several studies have demonstrated the relationship between NAFLD and coronary arterial disease (CAD). For example, a Dutch study of 1439 people, demonstrated the relationship between ALT at baseline and the 10-year incidence of CAD [9]. A Swedish study of 129 consecutive patients with biopsy proven NAFLD, over 13 years, demonstrated 8% absolute risk increase for cardiovascular mortality [10].

3.3 Non-alcoholic steatohepatitis

Hepatic steatosis, as detected by magnetic resonance spectroscopy, is found in 31% of adults in the United States [11]. The prevalence of steatosis tends to be higher among males and Hispanics. Non-alcoholic fatty liver disease is more frequent among people with diabetes (50%) and obesity (76%), and it is almost universal among diabetic people who are morbidly obese [12].

Non-alcoholic steatohepatitis (NASH) is an inflammatory disease that results from hepatic steatosis. It is characterized by macrovesicular steatosis, lobular inflammation, and hepatocellular ballooning [13], and is reversible, in its early stages, with weight loss. However, sustained liver injury leads to fibrosis and cirrhosis in 10–25% of affected individuals [14]. Liver biopsy is the only reliable method of diagnosing NASH. It is estimated that 12–20% of patients with hepatic steatosis will go on to develop NASH [15]. Of these, roughly one in eight will develop cirrhosis over the next 5 years.

Non-alcoholic fatty liver disease is generally asymptomatic, and it is only the development of cirrhosis that has clinical consequence. It has little or no impact on peri-operative outcomes. The natural history of disease progression from steatosis, to NASH to cirrhosis is unclear. Moreover, it has been demonstrated that regression of disease may occur, with lower levels of fibrosis being observed in 29% of patients, on sequential liver biopsy at a time interval of 2 years [16]. The presence of diabetes predicted disease progression in this cohort.

Why does NASH develop? Adipose tissue, and in particular visceral fat, is an endocrine, paracrine and immunologic organ. Obesity is a state of chronic inflammation. Insulin is an anti-inflammatory hormone. As we have seen, increased circulating free fatty acids (FFAs), derived from highly metabolic visceral fat, can reduce insulin activity and promote hepatic steatosis. Tissue macrophages invade adipose tissue and release tumor necrosis factor-alpha (TNF-α). This, in turn, causes the release of interleukin (IL-1), IL–6, and other cytokines. There is an alteration in the relative concentrations of adipose-derived hormones, collectively known as "adipokines" (Table 3.1). Leptin, the first adipokine described, is involved in the control of satiety and is markedly pro-inflammatory. Conversely, adiponectin, which is thought to be anti-inflammatory and enhances insulin sensitivity, is reduced in these people. Resistin, an adipokine that antagonizes insulin, is elevated. There are elevated levels of plasminogen activator inhibitor-1 (PAI-1), and increased C-reactive protein (CRP) levels, consistent with activation of inflammation. This adiopocytokine profile, as we shall see, is characteristic of the MetS, but is also seen in NAFLD.

The steatotic liver is thought to be vulnerable to secondary insults that may lead to NASH. The two-hit hypothesis proposed by Day and James remains the prevailing pathogenic theory [17]. First, accumulation of FFAs and triglycerides occurs within the liver. This represents the first hit. Subsequently, this fatty accumulation within the liver leads to chronic oxidative stress, the so-called second hit, which has been hypothesized to make the hepatocyte vulnerable to apoptosis or necrosis [17]. This may be induced by a number of mediators, including adipokines, cytokines, fatty acids, mitochondrial dysfunction, bacterial endotoxin, and vascular disturbance. These factors may be directly hepatotoxic or generate oxygen radicals with subsequent lipid peroxidation, cytokine induction, and liver damage.

The pathologic description of NASH was described by Brunt and colleagues, based on a review of liver biopsies from 51 patients with known disease

Table 3.1 a Non-alcoholic steatohepatitis activity grade

Grade	Steatosis	Ballooning	Inflammation
Mild, grade 1	1–2 (up to 66%)	Minimal	L: 1–2 P: none-mild
Moderate, grade 2	2–3 (>33%; may be >66%)	Present	L: 2 P: mild–moderate
Severe, grade 3	3	Marked	L: 3 P: mild–moderate

Steatosis: Grade 1: 33%; Grade 2: >33% <66%; Grade 3: 66%. L, lobular; P, portal. Adapted from: Ref [25].

Table 3.1b Non-alcoholic fatty liver disease – staging of fibrosis

Stage	Histologic description
0	No fibrosis
1a	Zone 3 perisinusoidal fibrosis, requires trichrome stain to identify
1b	Zone 3 perisinusoidal fibrosis, seen easily on H&E
1c	Periportal/portal fibrosis only
2	Zone 3 plus portal/periportal fibrosis
3	As above with bridging fibrosis
4	Cirrhosis

Adapted from: Ref [26].

(Table 3.1a) [18]. and was improved upon by Kleiner *et al*. in 2005 (Table 3.1b) [19].

3.4 From insulin resistance to type 2 diabetes

Insulin resistance is commonly associated with, but not unique to, obesity. By definition, there is reduced biologic activity in response to circulating insulin. Insulin is secreted mainly in response to plasma glucose. Thus, in order to maintain normal glucose homeostasis, circulating insulin levels rise, resulting in a medley of metabolic abnormalities including dyslipidemia, lipoprotein dysregulation, the MetS, and NAFLD. Patients that develop IR may be genetically susceptible, but a number of environmental factors may also trigger this problem including lifestyle, diet, stress, and smoking. Insulin resistance may result from chronic low-level inflammation, as described above. Obesity-associated adipocyte apoptosis appears to be the primary event underlying insulin insensitivity [20]. Macrophages infiltrate the adipocytes and hepatic tissue, perhaps a common pathway between insulin resistance and NAFLD. In many obese patients NAFLD, as we have seen, may precede and be responsible for IR.

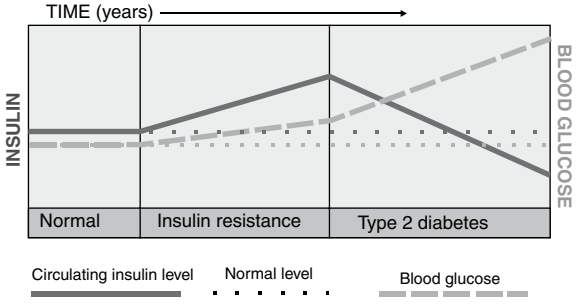

Figure 3.3 Development of type 2 diabetes.

The metabolic consequences of IR result in a progressive cycle of hyperglycemia, dyslipidemia, endothelial dysfunction, inflammation, and atherosclerosis. Simultaneously, as the pancreatic β-cells increase output to maintain normoglycemia, fatty deposition around these cells progressively reduces synthetic reserve [21]. Initially, a pre-diabetes state results, manifest by impaired fasting glucose and/or impaired glucose tolerance. Eventually the islet cells fail to produce sufficient insulin to maintain normoglycemia and diabetes results (Figure 3.3). Over time the β-cells burn out, and glucose and lipid homeostasis fails.

3.5 Fat distribution

The distribution of body fat has significant impact on the development of metabolic disease. Patients are divided into roughly two groups: those with peripheral (pear-shaped – gluteofemoral obesity) fat distribution, the majority of whom are female, and those with central (apple-shaped – abdominal obesity) fat distribution, the majority of whom are male. This is conventionally recorded in Whites as waist-to-hip ratio. A ratio of >1.0 in males, and > 0.85 in females suggests central obesity. Waist circumference is an indicator of visceral fat deposition. Emerging data suggests that this ratio may be a better predictor of risk of disease or death than BMI [22, 23]. For example, waist circumference correlates well with the presence of NAFLD [6]. Abnormal fat distribution plays a key role in the pathogenesis of MetS. Visceral fat by itself is a strong determinant of insulin sensitivity and B-cell function. Visceral adiposity, as measured by waist circumference, correlates better with the risk of diabetes or coronary vascular disease (CVD) than total obesity as measured by BMI [24]. In a study of 27 098 participants in 52 countries, waist-to-hip ratio showed a graded and highly significant association with myocardial infarction, and is a superior predictor of cardiac events than BMI [23].

Pischon and colleagues evaluated the association of general and abdominal adiposity with the risk of death in the European Prospective Investigation into Cancer and Nutrition (EPIC), a large cohort study in Europe [24]. They examined the association of BMI, waist circumference, and waist-to-hip ratio with the risk of death among 359 387 participants from nine countries. During a mean follow-up of 9.7 years, 14 723 participants died. After adjustment for BMI, waist circumference and waist-to-hip ratio, and hence visceral adiposity, were strongly associated with the risk of death. Relative risks among men and women in the highest quintile of waist circumference were: 2.05 (95% confidence interval [CI], 1.80–2.33) and 1.78 (95% CI, 1.56–2.04), respectively, and in the highest quintile of waist-to-hip ratio, the relative risks were 1.68 (95% CI, 1.53–1.84) and 1.51 (95% CI, 1.37–1.66), respectively. In models that included waist circumference or waist-to-hip ratio ($p < 0.001$), BMI remained significantly associated with the risk of death. These data suggest that both general adiposity and abdominal adiposity are associated with the risk of death. The associations of BMI with the risk of death were J-shaped, with higher risks of death observed in the lower and upper BMI categories than in the middle categories. In contrast, once general adiposity was adjusted for, abdominal fat distribution was positively associated with the risk of death. These associations tended to be stronger among participants with a lower BMI than among those with a higher BMI. Thus, measurement of both general and abdominal adiposity provides a better assessment of the risk of death, particularly among people with a lower BMI.

3.6 Metabolic syndrome

The term "metabolic syndrome" (MetS) refers to a collection of clinical findings that include central obesity, hypertension, dyslipidemia, and IR or impaired glucose tolerance (Figure 3.4). Taken together, these physiologic and metabolic derangements are believed to be associated with elevated risk for morbidity or death compared with the sum of the individual components. The International Diabetes Federation (IDF – www.idf.org) has described a syndrome as "a recognizable complex of symptoms and physical or biochemical findings for which a direct cause is not understood… the components coexist more frequently than would be expected by chance alone. When causal mechanisms are identified, the syndrome becomes a disease."

In 1988 Gerald Reaven explained how IR and compensatory hyperinsulinemia can lead to diverse

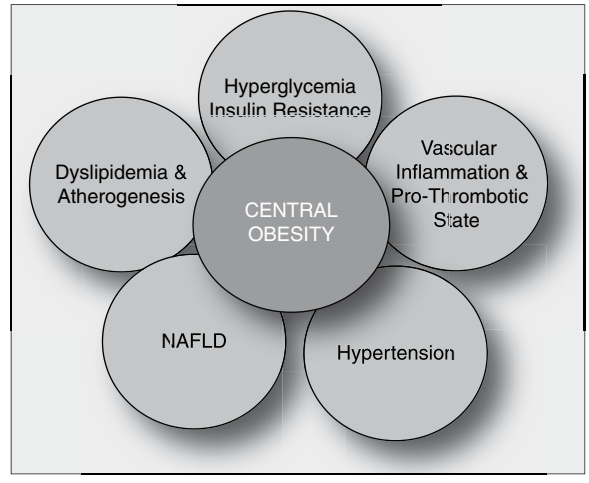

Figure 3.4 Components of the metabolic syndrome: NAFLD, non-alcoholic fatty liver disease.

metabolic abnormalities, T2D and cardiovascular disease [25]. The disease he described was initially known as "Syndrome X." This was confusing, as cardiologists used the same moniker to describe angina with normal coronary arteries. Reaven and others believed that IR was the common thread for this clustering of symptoms, presumably as the initiating process. Over the past 20 years the role of IR has become more peripheral and central obesity more prominent, perhaps reflecting the escalating awareness of the "obesity epidemic."

Several definitions of MetS currently exist. None are perfect and there is little agreement between them. This range of definitions has been problematic as population-based risk profiling studies have used different definitions with different results. Further, whether or not this cluster of symptoms truly represents an independent risk syndrome remains controversial.

The two most widely used definitions were proposed by the World Health Organization (WHO – Table 3.2) [26] and the National Cholesterol Education Program (NCEP – Table 3.3) [27]. A modification of the NCEP has been published [28, 29], and most recently the IDF has modified the WHO definition further (http://www.idf.org/webdata/docs/IDF_Meta_def_final.pdf) so that it is now much closer to the NCEP's. There are still some differences, such as how to treat waist circumference that the IDF requires and for which it uses ethnic-specific measures.

The NCEP-MetS was developed as a tool to identify individuals at high cardiovascular risk, taking into account the evidence of increased obesity and decreased

Table 3.2 Metabolic syndrome definitions: WHO/IDF models

World Health Organization criteria (1999)[a]
1. Must have abnormal glucose metabolism:
a. diabetes mellitus
b. impaired glucose tolerance
c. impaired fasting glucose insulin resistance
and two of the following:
1. Blood pressure: ≥ 140/90 mmHg
2. Dyslipidaemia:
a. triglycerides : ≥ 1.695 mmol l^{-1}
b. high-density lipoprotein cholesterol ≤ 0.9 mmol l^{-1} (male), ≤ 1.0 mmol l^{-1} (female)
3. Central obesity: waist:hip ratio > 0.90 (male); > 0.85 (female), and/or body mass index > 30 kg m^{-2}
4. Microalbuminuria: urinary albumin excretion ratio ≥ 20 mg min^{-1} or albumin:creatinine ratio ≥ 30 mg g^{-1}
IDF 2006
The International Diabetes Federation definitions. For a person to be defined as having the metabolic syndrome they must have:
1. Central obesity
a. waist circumference ≥ 94 cm for Europid men
b. waist circumference ≥ 80 cm for Europid women
c. (ethnicity specific values for other groups)
Plus *any two* of the following four factors:
1. Dyslipidemia, elevated triglycerides ≥ 150 mg dl^{-1} (1.7 mmol l^{-1}), or specific treatment for dysplipidemia
2. Dyslipidemia, reduced high-density lipoprotein:
a. < 40 mg dl^{-1} (1.03 mmol l^{-1}) in males
b. < 50 mg dl^{-1} (1.29 mmol l^{-1}) in females
c. or specific treatment for dyslipidemia
3. Hypertension: systolic blood pressure ≥ 130 or diastolic BP ≥ 85 mm Hg, or treatment of previously diagnosed hypertension
4. Elevated fasting plasma glucose ≥ 100 mg dl^{-1} (5.6 mmol l^{-1}), or previously diagnosed type 2 diabetes
a. If above 5.6 mmol l^{-1} or 100 mg dl^{-1}, OGTT is strongly recommended but is not necessary to define presence of the syndrome.

[a] Source: Ref [43].
OGTT, Oral Glucose Tolerance Test.

Table 3.3 Metabolic syndrome: National Cholesterol Education Program (AHA) definitions

NCEP I 2001
The USA National Cholesterol Education Program Adult Treatment Panel III (2001)[a] requires at least three of the following:
1. Central obesity defined by waist circumference:
a. ≥ 102 cm or 40 inches (male)
b. ≥ 88 cm or 36 inches(female)
2. Dyslipidemia: TG ≥ 1.695 mmol l^{-1} (150 mg dl^{-1})
3. Dyslipidemia:
a. HDL < 40 mg dl^{-1} (male)
b. HDL < 50 mg dl^{-1} (female)
4. Blood pressure ≥ 130/85 mmHg
5. Fasting plasma glucose ≥ 6.1 mmol l^{-1} (110 mg dl^{-1})
NCEP II (Updated) /AHA 2005[b]
1. Central obesity:
a. waist circumference: men ≥40 inches (102 cm)
b. waist circumference: women ≥ 35 inches (88 cm)
2. Dyslipidemia: triglycerides: ≥150 mg dl^{-1}
3. Dyslipidemia: reduced HDL :
a. Men ≤ 40 mg dl^{-1}
b. Women ≤50 mg dl^{-1}
4. Hypertension: ≥130/85 mm Hg or use of antihypertensives
5. Elevated fasting glucose: ≥ 100 mg d l^{-1} (5.6 mmol l^{-1}) or use of medication for hyperglycemia

[a] Source: Ref [44].
[b] Source: Refs [45,46].
AHA, American Heart Association; TG, triglygerides; HDL, high density lipoprotein.

physical activity around the world, whereas the WHO-MetS and the IDF-MetS were developed more as efforts to emphasize IR as a clinical risk paradigm. The NCEP definitions are more widely used in North America, and the WHO definitions, and its offspring, are more widely used in Europe.

What are the differences among the definitions (Tables 3.2 and 3.3)? The NCEP and the IDF definitions have a lower threshold for blood pressure (130/85 versus 140/90) than the WHO. The NCEP does not require waist circumference to be elevated on all patients, whereas the WHO and the IDF do. The NCEP does not require frank glucose intolerance or diabetes, whereas the WHO and the IDF do. And finally, the NCEP and the IDF do not require microalbuminuria, whereas the WHO does [27, 30].

Depending on which definition is used, between 25.1% [31] and 27% (NCEP definition)[32] of the population (WHO definition) have MetS. African American females and Mexican Americans of both genders are at particular risk. Amongst Finnish males the prevalence of MetS ranged from 8.8% (WHO definition) to 14.3% (NCEP definition) [29]. Patients with MetS were 2.9–3.3 times more likely to die of coronary arterial disease.

Obesity is not an essential component of MetS; however, there is a strong correlation between visceral fat deposits and MetS. Hence definitions of MetS emphasize

waist circumference rather than BMI. It is possible to be metabolically obese and normal weight, or obese without MetS (metabolically "healthy" obese) [33]. This distinction is important because MetS, not BMI, predicts future cardiovascular disease in women [34].

3.6.1 Metabolic syndrome and inflammation

The metabolic syndrome is an inflammatory disorder, and is associated with an increase in visceral adipose tissue mass. Adipose tissue produces adipokines and pro-inflammatory cytokines (Table 3.4). These include CRP, TNFα, plasma resistin, IL-6, and IL-18. Visfatin (also known as pre-B-cell colony-enhancing factor) is an adipokine that is highly expressed in visceral fat. Plasma visfatin has been reported to correlate with the degree of visceral adiposity in humans [35]. Anti-inflammatory adiponectin is depressed in MetS. Hence the MetS produces an inflammatory picture analogous to low grade sepsis.

Interestingly, there are preliminary data that this adipokine picture is associated with an increase in the risk of myocardial ischemia [36]. Recent studies have confirmed the contribution of inflammation to myocardial ischemia and infarction [37, 38] (Figure 3.5). The metabolic syndrome is associated with increased triglycerides (TGs), low HDLs and altered LDL size: these smaller less dense particles are more atherogenic. The enhanced secretion of IL-6 and TNF-α among others, results in more IR and lipolysis of adipose tissue TG stores, resulting in increased circulating FFAs. There is a strong relationship between NAFLD and the development of MetS [39]. Cytokines, including IL-6, are increased in the circulation and may enhance hepatic glucose production, the production of VLDL by the liver, and IR in muscle. High TGs in HDLs actually reduce the HDL size as TGs are hydrolyzed by hepatic lipase. Consequently HDL is filtered by the kidneys leading to reduced apolipoprotein A and HDL concentration. Cytokines and FFA also increase the production of fibrinogen and PAI-1 by the liver, complementing the overproduction of PAI-1 by adipose tissue. This results in a pro-thrombotic state.

3.6.2 MetS and cardiovascular risk

The combination of active inflammation, hypercoagulability, atherogenesis, hyperglycemia, and increased circulating lipid should be expected to increase cardiovascular risk (see Chapter 1).

Table 3.4 Adipocytokines associated with the metabolic syndrome.

Acute phase reactants
↑C-reactive protein
↑SAA
Adipokines
↓Adiponectin
↑Leptin
↑Resistin
Macrophage derived factors
↑Resistin
↑IL-1β
Pro-inflammatory cytokines and chemokines
↑TNF-α
↑IL-1, IL-6, IL-8, IL-10, IL-18
↑CCL2
Pro-thrombotic factors
↑PAL1
↑Fibrinogen
↑Factor VII

SAA, serum amyloid A; TNF-α, tumor necrosis factor alpha; IL, interleukin; CCI2, chemokine (C-C motif) ligand 2; PAI1, plasminogen activator inhibitor-1.

Patients with MetS are more likely to have major coronary events compared to those without MetS [40, 41, 42]. The presence of MetS predicts a significantly higher risk of cardiovascular mortality [43, 44]. The Framingham Heart Study followed a cohort of 3323 middle-aged adults for the development of new CVD, congestive heart disease, and T2D over an 8-year period [44]. In people without CVD or T2D at baseline, the prevalence of the MetS was 26.8% in men and 16.6% in women. For both men and women the presence of MetS predicted the development of CVD and T2D. The Cardiovascular Health Study followed 4258 elderly people, free of CVD, for an average of 15 years using a variety of definitions of MetS [45]. Subjects with MetS had a 22% higher mortality than those without. However, mortality was better predicted by the presence of hyperglycemia and hypertension than by the diagnosis of MetS. Subjects having both hypertension and elevated fasting glucose had 82% higher (82%) mortality. Another study looked at cardiac risk in men and women aged 50–75 years without diabetes or CVD at baseline 10 years earlier [46]. The NCEP I definition was associated with about a 2-fold increase in age-adjusted risk of

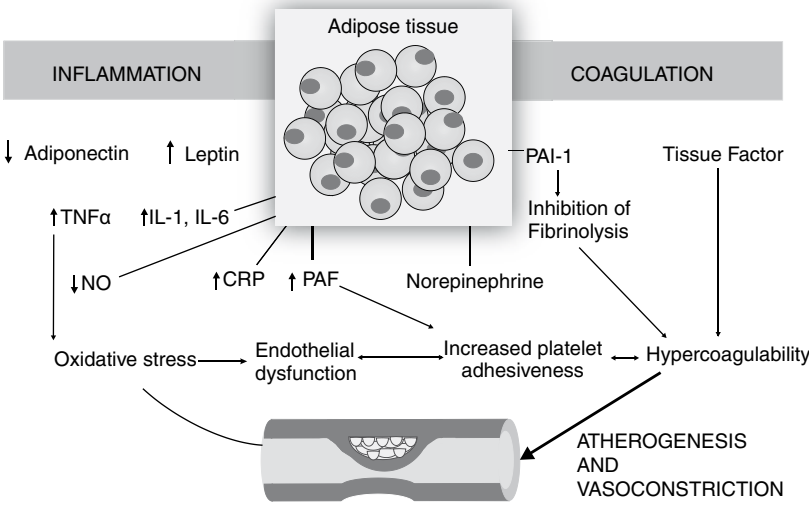

Figure 3.5 Atherogenesis and obesity: TNF, tumor necrosis factor; IL, interleukin; NO, nitric oxide; CRP, C reactive protein; PAI, plasminogen activation inhibitor; PAF, platelet activating factor.

fatal CVD in men and non-fatal CVD in women over that time period.

What about the risk of cerebrovascular disease? A Finnish group followed 1131 men, again with no history of CVD or diabetes, over an average of 14.3 years, and identified MetS using the NCEP I criteria [47]. There was 2.05-fold (95% CI, 1.03–4.11; $p = 0.042$) risk for all strokes and 2.41-fold (95% CI, 1.12–5.32; $p = 0.025$) risk for ischemic stroke. However, to obtain statistical significance, this data was adjusted for socioeconomic status, smoking, alcohol, and family history of coronary heart disease. Similar data were obtained when the WHO criteria were applied.

Treatment for MetS includes weight loss, achieved by diet, exercise, pharmacotherapy, or bariatric surgery. Certain drugs increase fat excretion, LDL production, or insulin sensitivity: these include fibrates, nicotinic acids, statins, and insulin sensitizers (Table 3.5) Thiazolidinediones, such as troglitazone and rosiglitazone, increase insulin sensitivity, and should, in theory, reverse many of the changes seen in MetS. They act as ligands for the gamma peroxisome proliferator-activated receptors [48]. These are nuclear receptors, predominantly found in adipose tissue. Thiazolidinediones reduce the secretion of non-esterified fatty acids and adipocytokines (Table 3.4) and increase the production of adiponectin. In addition, these agents increase HDL cholesterol, improve endothelial function and fibrinolysis, and decrease carotid intimal thickness. These agents may also lower blood pressure and redistribute fat away from the central compartment. However, fluid retention is a problem, and this may precipitate congestive heart failure. In addition, total body fat increases due to PPAR-gamma-associated adipogenesis. Finally, these agents may be carcinogenic, although there are no human data to support this [48].

3.6.3 Metabolic syndrome in the peri-operative period

Does MetS increase peri-operative risk? Surprisingly little data have been published. In a retrospective analysis of nearly 10 000 patients that had attended Texas Heart Institute over a 10-year period, patients were subdivided on the basis of BMI into overweight-obese and normal weight, and into diabetic and non-diabetic [49]. Obese patients were significantly younger than normal weight patients at the times of surgery, in line with previous similar studies. The diagnosis of diabetes was based on admission data or therapy. Obesity or diabetes, individually, did not confer additional risk to patients. In contrast, obesity and diabetes (type 1 or type 2) in combination were associated with an elevated risk of post-operative respiratory failure, atrial and ventricular arrhythmias, renal insufficiency, and leg wound infections. These data suggest that diabetes and obesity, as seen in the MetS, have synergistic risk. However, this study was retrospective over 10 years, and robust measures to diagnose diabetes and abdominal obesity were not used. Other studies that have looked at obesity and

Table 3.5 Pharmacotherapy for components of the metabolic syndrome.

Dyslipidemia	Hypertension	Diabetes	Anti-thrombotic agents	Obesity
Statins	Thiazide diuretics	Sulphonylureas	Aspirin	Orlistat
Ezetimibe	Beta-blockers	Metformin	Clopidogrel	Sibutramine
Bile-acid sequestrants	ACE inhibitors	Insulin		
Nicotinic acid	Angiotensin receptor blockers	Glitazones		
Fibrates	Calcium channel blockers	Prandial glucose regulators		
	Alpha-blockers			
	Imidazoline receptor agonists			

ACE, angiotension converting enzyme.

cardiac surgery have shown mixed outcomes [50–53], with only one large cohort study reporting increased peri-operative risk [54].

Long-term therapy for MetS includes lifestyle modification, weight loss, tight control of hypertension and diabetes, beta blockade, statin, and perhaps fibrate administration, nicotinic acid, and thiazolidinedione (insulin sensitizer) therapy. A question for those of use involved in peri-operative care is whether any or all of these interventions modulate peri-operative risk.

For the peri-operative clinician, scoring systems that define peri-operative risk are helpful in planning for and preventing peri-operative morbidity. Clearly, if MetS is to be a useful concept, it is in the peri-operative period, during which there is a controlled stress response, that it will be most widely applied. For example, we know that in a large cohort of patients, the prevalence of coronary arterial disease was 19.2% in patients with MetS and T2D, 13.9% with MetS alone, and 7.5% with diabetes alone [55]. The presence of CAD increases peri-operative risk [56]. Hence hypothetically, MetS should be considered an independent peri-operative risk factor.

Two problems derive from this. The first is the diagnosis of MetS: should all peri-operative patients that have central obesity be screened? Using the current definitions, this would require fasting blood glucose and fasting lipid profiles. Is this cost effective?

The second problem is that once MetS has been diagnosed, what intervention is likely to reduce peri-operative morbidity? Accumulated data on pre-operative pharmacotherapy has yielded disappointing results. Following early promising reports by Mangano [57] and Poldermans [58], peri-operative prophylactic beta blockade, for patients with known or suspected coronary heart disease, became widely used [59, 60, 61]. However, the majority of patients undergoing non-cardiac surgery do not appear to be at elevated risk for cardiac complications. Consequently, many patients received beta blockade that did not necessarily require such therapy. Conflicting data has been published. For example, Yang and colleagues, investigated beta blockade in patients undergoing major vascular surgery, and were unable to find differences in outcomes [62]. These data conflicted with those of Poldermans *et al.* However, the latter group took great care to identify patients a priori with significant CAD [63]. Similar results were reported in a study of nearly 1000 patients by Juul *et al.* [64], and in a population-based study of nearly 800 000 patients [65]. In order to clarify whether or not beta blockade decreased or increased the risk of peri-operative events, the POISE study was performed [66].

The POISE trial was a prospective randomized control trial of 8351 patients in 190 hospitals in 23 countries [66]. Patients with, or at risk of, atherosclerotic disease who were undergoing non-cardiac surgery were randomized to receive extended-release metoprolol (n = 4174) or placebo (n = 4177) started 2–4 hours before surgery and continued for 30 days. Administration of metoprolol was associated with a lower incidence of myocardial infarction (absolute risk reduction 1.2%, p <0.001), but a higher mortality rate (absolute risk increase of 0.8%; p < 0.04) and an increase in the risk of stroke (absolute risk increase 0.5%; p <0.01). Meta-analyses of published trials of peri-operative beta blockers demonstrated that although beta blockade appeared to reduce the peri-operative risk of myocardial infarction, it did so at elevated risk for mortality and stroke [66].

Peri-operative beta blockade can only be recommended for patients already receiving this therapy, and it should not be stopped in the peri-operative period.

Dyslipidemia is a core component of MetS. Statin therapy is well established for prevention of cardiovascular disease. Statins reduce LDL levels, and reduce inflammation associated with oxidized lipoprotein. Statins may also reduce post-operative mortality and morbidity via a pleiotropic (non-lipid-lowering) effect,

resulting in plaque stabilization. Finally statins may reduce overall inflammation, associated with both surgery and MetS.

Does the peri-operative administration of "statins" reduce peri-operative risk? To date no randomized controlled trial has satisfactorily proven the effectiveness of statin therapy in the peri-operative period, and although retrospective analyses have suggested a benefit, this is likely overestimated. Meta-analysis of data from 12 retrospective and 3 prospective trials (n = 223 010 patients), found that pre-operative statin therapy was associated with 38% and 59% reduction in the risk of mortality after cardiac (1.9% vs. 3.1%; p = 0.0001) and vascular (1.7% vs. 6.1%; p = 0.0001) surgery, respectively [67]. When including non-cardiac surgery, a 44% reduction in mortality (2.2% vs. 3.2%; p = 0.0001) was observed.

Three large retrospective cohort reviews [63, 68, 69] have associated peri-operative statin therapy with reduced cardiovascular risk. However, when one considers that national and international organizations recommend the routine use of statins for prophylaxis against the development of cardiovascular disease, these studies may highlight statins as a reflection of quality of healthcare, and implicate inadequate pre-operative optimization rather than specific drug-related benefit.

Kapoor and colleagues [70] systematically reviewed 18 studies – 2 randomized trials (n = 177), 15 cohort studies (n = 799 632), and 1 case-control study (n = 480) – to assess whether statins provide peri-operative cardiovascular protection. In the randomized trials, the summary odds ratio for death or acute coronary syndrome during the peri-operative period with statin use was 0.26 (95% CI 0.07–0.99) and the summary odds ratio in the cohort studies was 0.70 (0.57–0.87). It is important to note that the indication, dose, duration, and side effect profile of statins were not reported in these studies.

A single prospective study of peri-operative statin therapy was performed on 100 patients who were randomly assigned to receive 20 mg atorvastatin or placebo once a day for 45 days, irrespective of their serum cholesterol concentration [71]. Vascular surgery was performed on average 30 days after randomization, and patients were prospectively followed up over 6 months. The incidence of cardiac events was more than three times higher with placebo (26.0%) compared with atorvastatin (8.0%; p = 0.031). This study has been criticized for an unexpectedly high event rate in the control group (18% for in-hospital cardiac death and non-fatal myocardial infarction) and a remarkably low incidence of events in the treatment group. Data was not presented detailing the number of patients in the control group whose statins were stopped pre-operatively.

It seems that the major benefit of statins in the peri-operative period arises from *not stopping* these drugs when previously prescribed. Studies have demonstrated that acute statin withdrawal increases markers of inflammation and oxidative stress, and that statin withdrawal during unstable periods is associated with an increased risk of adverse cardiac events [72, 73]. A retrospective study of peri-operative statin withdrawal in vascular surgical patients reported an odds ratio associated with the use of statins to predict post-operative myocardial infarction as 2.1 (95% CI 1.1–3.8) in the discontinuation group and 0.38 (95% CI 0.15–0.98) in the continuation group [74]. Statin discontinuation in vascular surgery patients was associated with an increased risk for post-operative troponin release, and the combination of myocardial infarction and cardiovascular death [75]. These data suggest that withdrawal of statins greatly increases peri-operative risk.

Finally, the third component of MetS – dysregulation of glucose metabolism, may be amenable to therapy, and that is the focus of the next section.

3.7 Peri-operative hyperglycemia

Hyperglycemia should be considered a "normal" response to tissue injury. However, considerable interest exists in the management of blood glucose in peri-operative medicine and critical illness based on a number of observations. Should blood glucose levels be tightly controlled in obese and metabolically obese patients?

Although there are no data implicating stress hyperglycemia and adverse outcomes in bariatric surgery, substantial data exists in other clinical and laboratory conditions. Hyperglycemia can directly affect fluid balance, by inducing diuresis leading to dehydration. Hyperglycemia can induce immune dysfunction, by promoting inflammation due to induced abnormalities of white cell function. These include granulocyte adhesion, chemotaxis, phagocytosis, respiratory burst, and superoxide formation and intracellular killing. A limitation of these claims is that the studies were performed in diabetic patients, not those with stress hyperglycemia or impaired glucose tolerance: immune suppression may result from the disease – one of absolute or relative insulin deficiency, rather than the glucose.

In the clinical arena there are accumulating data that hyperglycemia, and poor control of diabetes, results in worse outcomes from myocardial ischemia

and stroke [76]. In the trauma population, a series of studies have associated the magnitude of hyperglycemia with adverse outcomes [77]. Two very distinct observations can be derived from these data: hyperglycemia causes adverse outcomes or hyperglycemia is a surrogate marker of severity of illness, or inadequacy of physiologic reserve. In the latter hypothesis, stress hypoglycemia is analogous to stress hypoalbuminemia – the magnitude of change from homeostatic norm is indicative of degree of injury.

In view of the association between adverse outcomes and hyperglycemia, it has been proposed that aggressive glycemic control may improve outcomes. Analogously, intensive insulin therapy may be used to achieve glycemic control.

Insulin has significant anti-inflammatory properties [78]. It has powerful antioxidant activity. Insulin suppresses several pro-inflammatory transcription factors (NF-kB [nuclear factor-kappa B], EGR-1 [early growth response 1], AP-1 [activating protein 1]) and reduces the quantity of circulating cytokines. As MetS is an inflammatory disease, one would anticipate that insulin would reverse many of the adverse metabolic consequence. Treatment of T2D with insulin for 2 weeks reduced CRP and chemotactic protein-1 [79]. Treatment of severe hyperglycemia, associated with marked increases in inflammatory mediators, with insulin led to a marked reduction in inflammatory mediators [80]. Animal models of sepsis and thermal injury treated with insulin demonstrate similar reductions in inflammatory mediators [81, 82].

Obese patients with insulin resistant T2D have larger infarcts than non-diabetics. In a rat model of myocardial ischemia, the introduction of insulin into the reperfusion fluid reduced infarct size by 50% [83]. A similar effect was seen in humans given insulin, TPA, and heparin [83, 84].

Insulin appears to be cardioprotective in the presence of ischemia [85, 86]. Insulin therapy in peri-operative, and, in particular, cardiothoracic surgical patients, was associated with a significant reduction in the risk of death [87]. Enthusiasm for insulin therapy, rather than glycemic control, must be tempered by the knowledge that increased insulin administration is positively associated with death in the intensive care unit (ICU) regardless of the prevailing blood glucose level [88]. Additionally, it remains unclear whether these data may be applicable in other clinical situations.

Does intensive insulin therapy improve outcomes in peri-operative and critically ill patients? Meticulous control of blood glucose significantly reduces the incidence of deep sternal wound infections [89, 90]. The same group demonstrated a significant reduction in peri-operative mortality in diabetic patients undergoing cardiac surgery that were managed with intensive insulin therapy [91].

The case for intensive insulin therapy was advanced by the work of Van Den Berghe and colleagues [87]. Patients in a surgical ICU were randomized into two groups: a conventional therapy group that received an insulin drip if blood glucose exceeded 215 mg dl^{-1}, and the level was adjusted to maintain blood glucose of 180–200 mg dl^{-1}. The second group received "intensive insulin therapy": an insulin drip was started if blood glucose exceeded 100 mg dl^{-1}, and the level was adjusted to maintain blood glucose at 80–100 mg dl^{-1}. All patients were given dextrose on day 1 and fed on day 2. The majority of patients enrolled into this study had undergone cardiothoracic surgery. Overall, intensive insulin therapy resulted in an absolute risk reduction of death of 3.4% (4.6% versus 8.0% $p < 0.04$). Subgroup analysis suggested that this mortality difference accrued principally to patients with prolonged ICU stays. In effect this referred to patients that were critically ill rather than those that underwent a standard peri-operative stress response. Subsequent data suggested that the mechanism of benefit was endothelial protection and reduced hepatocyte mitochondrial damage [92, 93].

Two follow-up studies ensued. The first evaluated whether the outcome benefit resulted from blood glucose control or insulin and concluded that glycemic control was more important than insulin dose [94]. Increasing insulin dose was related to increased incidence of renal failure [94]. Increased insulin administration is positively associated with death in the ICU regardless of the prevailing blood glucose level [88]. In a study of intensive insulin therapy in the medical ICU, there was no statistical significant difference in mortality outcomes (37.3% in the intensive insulin therapy group versus 40.0% in the conventional therapy group ($p = 0.33$) [95]).

Currently there is insufficient data to support tight glycemic control for the majority of peri-operative patients, perhaps with the exception of those undergoing cardiac or neurosurgery.

3.8 Conclusions

Obesity is a metabolic disease that arises from excessive energy consumption. The development of NAFLD

appears to be an early indicator of escalating endocrine and metabolic dysfunction. Fatty liver results in IR and IR results in fatty liver. This persists over time as NAFLD and T2D diabetes develop. Weight loss, bariatric surgery, and exogenous insulin slow down and reverse the progression.

Obesity increases the risk for cardiovascular, cerebrovascular, and neoplastic disease. This probably results from a combination of dyslipidemia, dysregulation of glycemic control, and ongoing inflammation associated with adipocytokines. Central obesity closely correlates with cardiovascular risk, and is the key component of a constellation of symptoms known as the MetS. The presence of a large reservoir of metabolically active visceral fat appears to be pathgnomonic of this disease. Although subject to a variety of non-interchangeable definitions, MetS is associated with an elevated risk of cardiovascular disease. Nonetheless, many clinicians argue that this risk is no more than would be predicted by the individual components. There is little or no epidemiologic data available regarding the diagnosis of MetS and peri-operative risk. No guidelines are available. Risk reduction associated with modulation of the specific components of this syndrome, cardiovascular disease, dyslipidemia, and hyperglycemia, are currently in a state of flux. It is unclear whether, in the absence of angiographically demonstrable coronary arterial disease, beta blockade should be commenced pre-operatively. There are no prospective studies on the utility of statins. Neither beta blockers nor statins should be stopped peri-operatively, as epidemiologic data suggest rebound risk effects. Finally, although peri-operative hyperglycemia is widely believed to be associated with adverse outcomes, in this patient population the risk of hypoglycemia should not be discounted. Tight glycemic control cannot be recommended. However, moderate glycemic control (in the range of 100–150 mg dl^{-1}), particularly in patients undergoing cardiac and neurosurgery is likely beneficial.

References

1. Schwarz JM, Linfoot P, Dare D, Aghajanian K. Hepatic de novo lipogenesis in normoinsulinemic and hyperinsulinemic subjects consuming high-fat, low-carbohydrate and low-fat, high-carbohydrate isoenergetic diets. *Am J Clin Nutr* 2003; **77**: 43–50.
2. Juurinen L, Kotronen A, Graner M, Yki-Jarvinen H. Rosiglitazone reduces liver fat and insulin requirements and improves hepatic insulin sensitivity and glycemic control in patients with type 2 diabetes requiring high insulin doses. *J Clin Endocrinol Metabol* 2008; **93**: 118–24.
3. Raper HS, Smith EC. The direct action of insulin on fat metabolism. *J Physiol* 1925; **60**: 41–9.
4. Hollingsworth KG, Abubacker MZ, Joubert I, Allison MED, Lomas DJ. Low-carbohydrate diet induced reduction of hepatic lipid content observed with a rapid non-invasive MRI technique. *Br J Radiol* 2006; **79**: 712–5.
5. Petersen KF, Dufour S, Befroy D, Lehrke M, Hendler RE, Shulman GI. Reversal of nonalcoholic hepatic steatosis, hepatic insulin resistance, and hyperglycemia by moderate weight reduction in patients with type 2 diabetes. *Diabetes* 2005; **54**: 603–8.
6. Kotronen A, Yki-Jarvinen H. Fatty liver: A novel component of the metabolic syndrome. *Arterioscler Thromb Vasc Biol* 2008; **28**: 27–38.
7. Sattar N, McConnachie A, Ford I, *et al*. Serial metabolic measurements and conversion to type 2 diabetes in the west of Scotland Coronary Prevention Study: Specific elevations in alanine aminotransferase and triglycerides suggest hepatic fat accumulation as a potential contributing factor. *Diabetes* 2007; **56**: 984–91.
8. Shibata M, Kihara Y, Taguchi M, Tashiro M, Otsuki M. Nonalcoholic fatty liver disease is a risk factor for type 2 diabetes in middle-aged Japanese men. *Diabetes Care* 2007; **30**: 2940–4.
9. Schindhelm RK, Dekker JM, Nijpels G, Heine RJ, Diamant M. No independent association of alanine aminotransferase with risk of future type 2 diabetes in the Hoorn study. *Diabetes Care* 2005; **28**: 2812.
10. Ekstedt M, Franzen LE, Mathiesen UL, *et al*. Long-term follow-up of patients with NAFLD and elevated liver enzymes. *Hepatology* 2006; **44**: 865–73.
11. Browning JD, Szczepaniak LS, Dobbins R, *et al*. Prevalence of hepatic steatosis in an urban population in the United States: impact of ethnicity. *Hepatology* 2004; **40**: 1387–95.
12. Adams LA, Angulo P, Lindor KD. Nonalcoholic fatty liver disease. *CMAJ* 2005; **172**: 899–905.
13. Neuschwander-Tetri BA, Caldwell SH. Nonalcoholic steatohepatitis: summary of an AASLD Single Topic Conference. *Hepatology* 2003; **37**: 1202–19.
14. Moller DE, Kaufman KD. Metabolic syndrome: A clinical and molecular perspective. *Annu Rev Med* 2005; **56**: 45–62.
15. Day CP. Non-alcoholic fatty liver disease: current concepts and management strategies. *Clin Med* 2006; **6**: 19–25.
16. Adams LA, Sanderson S, Lindor KD, Angulo P. The histological course of nonalcoholic fatty liver disease: a longitudinal study of 103 patients with sequential liver biopsies. *J Hepatol* 2005; **42**: 132–8.

17. Day CP, James OF. Steatohepatitis: a tale of two "hits"? *Gastroenterology* 1998; **114**: 842–5.
18. Brunt EM, Janney CG, Di Bisceglie AM, Neuschwander-Tetri BA, Bacon BR. Nonalcoholic steatohepatitis: a proposal for grading and staging the histological lesions. *Am J Gastroenterol* 1999; **94**: 2467–74.
19. Kleiner DE, Brunt EM, Van NM, *et al*. Design and validation of a histological scoring system for nonalcoholic fatty liver disease. *Hepatology* 2005; **41**: 1313–21.
20. Martyn JA, Kaneki M, Yasuhara S. Obesity-induced insulin resistance and hyperglycemia: etiologic factors and molecular mechanisms. *Anesthesiology* 2008; **109**: 137–48.
21. Boden G. Role of fatty acids in the pathogenesis of insulin resistance and NIDDM. *Diabetes* 1997; **46**: 3.
22. Wang Y, Rimm EB, Stampfer MJ, Willett WC, Hu FB. Comparison of abdominal adiposity and overall obesity in predicting risk of type 2 diabetes among men. *Am J Clin Nutr* 2005; **81**: 555–63.
23. Yusuf S, Hawken S, Èunpuu S, *et al*. Obesity and the risk of myocardial infarction in 27,000 participants from 52 countries: a case-control study. *Lancet* **366**: 1640–9.
24. Pischon T, Boeing H, Hoffmann K, *et al*. General and abdominal adiposity and risk of death in Europe. *N Engl J Med* 2008; **359**: 2105–20.
25. Reaven GM. Banting lecture 1988. Role of insulin resistance in human disease. *Diabetes* 1988; **37**: 1595–607.
26. Alberti KG, Zimmet PZ. Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: diagnosis and classification of diabetes mellitus provisional report of a WHO consultation. *Diabet Med* 1998; **15**: 539–53.
27. Third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood pressure in adults (Adult Treatment Panel III): final report. *Circulation* 2002; **106**: 3143.
28. Grundy SM, Brewer HB, Cleeman JI, Smith SC, Lenfant C. Definition of metabolic syndrome: Report of the National Heart, Lung, and Blood Institute/American Heart Association. *Circulation* 2004; **109**: 433–8.
29. Grundy SM, Cleeman JI, Daniels SR, *et al*. Diagnosis and management of the metabolic syndrome: An American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation* 2005; **112**: 2735–52.
30. Grundy S, Hansen B, Smith S. AHA/NHLBI/ADA conference proceedings: clinical management of metabolic syndrome. Report of the American Heart Association/National Heart, Lung, and Blood Institute/ American Diabetes Association Conference on Scientific Issues Related to Management. *Circulation* 2004; **109**: 551.
31. Ford E, Giles W. A comparison of the prevalence of the metabolic syndrome using two proposed definitions. *Diabetes Care* 2003; **26**: 575.
32. Ford ES, Giles WH, Mokdad AH. Increasing prevalence of the metabolic syndrome among US adults. *Diabetes Care* 2004; **27**: 2444–9.
33. Karelis AD, St Pierre DH, Conus F, Rabasa-Lhoret R, Poehlman ET: Metabolic and body composition factors in subgroups of obesity: what do we know? *J Clin Endocrinol Metab* 2004; **89**: 2569–75.
34. Kip KE, Marroquin OC, Kelley DE, *et al*. Clinical importance of obesity versus the metabolic syndrome in cardiovascular risk in women: A report from the Women's Ischemia Syndrome Evaluation (WISE) Study. *Circulation* 2004; **109**: 706–13.
35. Koh KK, Han SH, Quon MJ. Inflammatory markers and the metabolic syndrome: insights from therapeutic interventions. *J Amer Coll Cardiol* 2005; **46**: 1978–85.
36. Pischon T, Girman CJ, Hotamisligil GS, Rifai N, Hu FB, Rimm EB. Plasma adiponectin levels and risk of myocardial infarction in men. *JAMA* 2004; **291**: 1730–7.
37. Pai JK, Pischon T, Ma J, *et al*. Inflammatory markers and the risk of coronary heart disease in men and women. *N Engl J Med* 2004; **351**: 2599–610.
38. Ridker PM, Rifai N, Pfeffer M, Sacks F, Lepage S, Braunwald E. Elevation of tumor necrosis factor-α and increased risk of recurrent coronary events after myocardial infarction. *Circulation* 2000; **101**: 2149–53.
39. Hamaguchi M, Kojima T, Takeda N, *et al*. The metabolic syndrome as a predictor of nonalcoholic fatty liver disease. *Ann Intern Med* 2005; **143**: 722–8.
40. Girman C, Rhodes T, Mercuri M. The metabolic syndrome and risk of major coronary events in the Scandinavian Simvastatin Survival Study (4S) and the Air Force/Texas Coronary Atherosclerosis Prevention Study (AFCAPS/TexCAPS). *Am J Cardiol* 2004; **93**: 136.
41. McNeill AM, Katz R, Girman CJ, *et al*. Metabolic syndrome and cardiovascular disease in older people: The cardiovascular health study. *J Am Geriatr Soc* 2006; **54**: 1317–24.
42. Sundstrom J, Riserus U, Byberg L, Zethelius B, Lithell H, Lind L. Clinical value of the metabolic syndrome for long term prediction of total and cardiovascular mortality: prospective, population based cohort study. *BMJ* 2006; **332**: 878–82.
43. Huang KC, Lee LT, Chen CY, Sung PK. All-cause and cardiovascular disease mortality increased with metabolic syndrome in Taiwanese. *Obesity (Silver Spring)* 2008; **16**: 684–9.

44. Wilson PW, D'Agostino RB, Parise H, Sullivan L, Meigs JB. Metabolic syndrome as a precursor of cardiovascular disease and type 2 diabetes mellitus. *Circulation* 2005; **112**: 3066–72.
45. Mozaffarian D, Kamineni A, Prineas RJ, Siscovick DS. Metabolic syndrome and mortality in older adults: the Cardiovascular Health Study. *Arch Intern Med* 2008; **168**: 969–78.
46. Dekker JM, Girman C, Rhodes T, *et al*. Metabolic syndrome and 10-year cardiovascular disease risk in the Hoorn Study. *Circulation* 2005; **112**: 666–73.
47. Kurl S, Laukkanen JA, Niskanen L, *et al*. Metabolic syndrome and the risk of stroke in middle-aged men. *Stroke* 2006; **37**: 806–11.
48. Grundy SM. Drug therapy of the metabolic syndrome: minimizing the emerging crisis in polypharmacy. *Nat Rev Drug Discov* 2006; **5**: 295–309.
49. Pan W, Hindler K, Lee VV, Vaughn WK, Collard CD. Obesity in diabetic patients undergoing coronary artery bypass graft surgery is associated with increased postoperative morbidity. *Anesthesiology* 2006; **104**: 441–7.
50. Birkmeyer NJ, Charlesworth DC, Hernandez F, *et al*. Obesity and risk of adverse outcomes associated with coronary artery bypass surgery. Northern New England Cardiovascular Disease Study Group. *Circulation* 1998; **97**: 1689–94.
51. Jin R, Grunkemeier GL, Furnary AP, Handy JR, Jr. Is obesity a risk factor for mortality in coronary artery bypass surgery? *Circulation* 2005; **111**: 3359–65.
52. Kim J, Hammar N, Jakobsson K, Luepker RV, McGovern PG, Ivert T. Obesity and the risk of early and late mortality after coronary artery bypass graft surgery. *Am Heart J* 2003; **146**: 555–60.
53. Reeves BC, Ascione R, Chamberlain MH, Angelini GD. Effect of body mass index on early outcomes in patients undergoing coronary artery bypass surgery. *J Amer Coll Cardiol* 2003; **42**: 668–76.
54. Prabhakar G, Haan CK, Peterson ED, Coombs LP, Cruzzavala JL, Murray GF. The risks of moderate and extreme obesity for coronary artery bypass grafting outcomes: a study from the Society of Thoracic Surgeons' database. *Ann Thorac Surg* 2002; **74**: 1125–30.
55. Alexander CM, Landsman PB, Teutsch SM, Haffner SM. NCEP-defined metabolic syndrome, diabetes, and prevalence of coronary heart disease among NHANES III participants age 50 years and older. *Diabetes* 2003; **52**: 1210–4.
56. Eagle KA, Berger PB, Calkins H, *et al*. ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery – executive summary: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). *J Amer Coll Cardiol* 2002; **39**: 542–53.
57. Mangano DT, Layug EL, Wallace A, Tateo I. The Multicenter Study of Perioperative Ischemia Research Group: Effect of atenolol on mortality and cardiovascular morbidity after noncardiac surgery. *N Engl J Med* 1996; **335**: 1713–21.
58. Poldermans D, Boersma E, Bax JJ, *et al*. The Dutch Echocardiographic Cardiac Risk Evaluation Applying Stress Echocardiography Study Group: The effect of bisoprolol on perioperative mortality and myocardial infarction in high-risk patients undergoing vascular surgery. *N Engl J Med* 1999; **341**: 1789–94.
59. Fleisher LA, Beckman JA, Brown KA, *et al*. ACC/AHA 2006 guideline update on perioperative cardiovascular evaluation for noncardiac surgery: Focused update on perioperative beta-blocker therapy. A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to update the 2002 guidelines on perioperative cardiovascular evaluation for noncardiac surgery) developed in collaboration with the American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, and Society for Vascular Medicine and Biology. *J Amer Coll Cardiol* 2006; **47**: 2343–55.
60. Devereaux PJ, Goldman L, Cook DJ, Gilbert K, Leslie K, Guyatt GH. Perioperative cardiac events in patients undergoing noncardiac surgery: a review of the magnitude of the problem, the pathophysiology of the events and methods to estimate and communicate risk. *CMAJ* 2005; **173**: 627–34.
61. Eagle KA, Berger PB, Calkins H, *et al*. ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery – executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). *J Am Coll Cardiol* 2002; **39**: 542–53.
62. Yang H, Raymer K, Butler R, Parlow J, Roberts R. The effects of perioperative [beta]-blockade: Results of the Metoprolol after Vascular Surgery (MaVS) study, a randomized controlled trial. *Am Heart J* 2006; **152**: 983–90.
63. Poldermans D, Bax JJ, Kertai MD, *et al*. Statins are associated with a reduced incidence of perioperative mortality in patients undergoing major noncardiac vascular surgery. *Circulation* 2003; **107**: 1848–51.

64. Juul AB, Wetterslev J, Gluud C, *et al*. Effect of perioperative beta blockade in patients with diabetes undergoing major non-cardiac surgery: randomised placebo controlled, blinded multicentre trial. *BMJ* 2006; **332**: 1482.
65. Lindenauer PK, Pekow P, Wang K, Mamidi DK, Gutierrez B, Benjamin EM: Perioperative beta-blocker therapy and mortality after major noncardiac surgery. *N Engl J Med* 2005; **353**: 349–61.
66. Devereaux PJ, Yang H, Yusuf S, *et al*. Effects of extended-release metoprolol succinate in patients undergoing non-cardiac surgery (POISE trial): a randomised controlled trial. *Lancet* 2008; **371**: 1839–47.
67. Hindler K, Shaw AD, Samuels J, Fulton S, Collard CD, Riedel B. Improved postoperative outcomes associated with preoperative statin therapy. *Anesthesiology* 2006; **105**: 1260–72.
68. Lindenauer PK, Pekow P, Wang K, Gutierrez B, Benjamin EM. Lipid-lowering therapy and in-hospital mortality following major noncardiac surgery. *JAMA* 2004; **291**: 2092–9.
69. O'Neil-Callahan K, Katsimaglis G, Tepper MR, *et al*. Statins decrease perioperative cardiac complications in patients undergoing noncardiac vascular surgery: the Statins for Risk Reduction in Surgery (StaRRS) study. *J Am Coll Cardiol* 2005; **45**: 336–42.
70. Kapoor AS, Kanji H, Buckingham J, Devereaux PJ, McAlister FA. Strength of evidence for perioperative use of statins to reduce cardiovascular risk: systematic review of controlled studies. *BMJ* 2006; **333**: 1149.
71. Durazzo AE, Machado FS, Ikeoka DT, De *et al*. Reduction in cardiovascular events after vascular surgery with atorvastatin: a randomized trial. *J Vasc Surg* 2004; **39**: 967–75.
72. Heeschen C, Hamm CW, Laufs U, Snapinn S, Bohm M, White HD. Withdrawal of statins increases event rates in patients with acute coronary syndromes. *Circulation* 2002; **105**: 1446–52.
73. Spencer FA, Allegrone J, Goldberg RJ, *et al*. Association of statin therapy with outcomes of acute coronary syndromes: the GRACE study. *Ann Intern Med* 2004; **140**: 857–66.
74. Le MY, Godet G, Coriat P, *et al*. The impact of postoperative discontinuation or continuation of chronic statin therapy on cardiac outcome after major vascular surgery. *Anesth Analg* 2007; **104**: 1326–33.
75. Schouten O, Hoeks SE, Welten GM, *et al*. Effect of statin withdrawal on frequency of cardiac events after vascular surgery. *Am J Cardiol* 2007; **100**: 316–20.
76. Lipshutz AK, Gropper MA. Perioperative glycemic control: an evidence-based review. *Anesthesiology* 2009; **110**: 408–21.
77. Baranov D, Neligan P: Trauma and aggressive homeostasis management. *Anesthesiol Clin* 2007; **25**: 49–63, viii.
78. Jeschke MG, Klein D, Bolder U, Einspanier R. Insulin attenuates the systemic inflammatory response in endotoxemic rats. *Endocrinology* 2004; **145**: 4084–93.
79. Takebayashi K, Aso Y, Inukai T. Initiation of insulin therapy reduces serum concentrations of high-sensitivity C-reactive protein in patients with type 2 diabetes. *Metabolism* 2004; **53**: 693–9.
80. Stentz FB, Umpierrez GE, Cuervo R, Kitabchi AE. Proinflammatory cytokines, markers of cardiovascular risks, oxidative stress, and lipid peroxidation in patients with hyperglycemic crises. *Diabetes* 2004; **53**: 2079–86.
81. Jeschke MG, Klein D, Bolder U, Einspanier R. Insulin attenuates the systemic inflammatory response in endotoxemic rats. *Endocrinology* 2004; **145**: 4084–93.
82. Jeschke MG, Einspanier R, Klein D, Jauch KW. Insulin attenuates the systemic inflammatory response to thermal trauma. *Mol Med* 2002; **8**: 443–50.
83. Jonassen AK, Sack MN, Mjos OD, Yellon DM. Myocardial protection by insulin at reperfusion requires early administration and is mediated via Akt and p70s6 kinase cell-survival signaling. *Circ Res* 2001; **89**: 1191–8.
84. Chaudhuri A, Janicke D, Wilson MF, *et al*. Anti-inflammatory and profibrinolytic effect of insulin in acute ST-segment-elevation myocardial infarction. *Circulation* 2004; **109**: 849–54.
85. Jonassen AK, Sack MN, Mjos OD, Yellon DM. Myocardial protection by insulin at reperfusion requires early administration and is mediated via Akt and p70s6 kinase cell-survival signaling. *Circ Res* 2001; **89**: 1191–8.
86. Lazar HL, Chipkin SR, Fitzgerald CA, Bao Y, Cabral H, Apstein CS. Tight glycemic control in diabetic coronary artery bypass graft patients improves perioperative outcomes and decreases recurrent ischemic events. *Circulation* 2004; **109**: 1497–502.
87. Van den Berghe G, Wouters P, Weekers F, *et al*. Intensive insulin therapy in the critically ill patients. *N Engl J Med* 2001; **345**: 1359–67.
88. Finney SJ, Zekveld C, Elia A, Evans TW. Glucose control and mortality in critically ill patients. *JAMA* 2003; **290**: 2041–7.
89. Zerr KJ, Furnary AP, Grunkemeier GL, Bookin S, Kanhere V, Starr A. Glucose control lowers the risk of wound infection in diabetics after open heart operations. *Ann Thorac Surg* 1997; **63**: 356–61.
90. Furnary AP, Zerr KJ, Grunkemeier GL, Starr A. Continuous intravenous insulin infusion reduces the

incidence of deep sternal wound infection in diabetic patients after cardiac surgical procedures. *Ann Thorac Surg* 1999; **67**: 352–60.

91. Furnary AP, Gao G, Grunkemeier GL, *et al*. Continuous insulin infusion reduces mortality in patients with diabetes undergoing coronary artery bypass grafting. *J Thorac Cardiovasc Surg* 2003; **125**: 1007–21.
92. Langouche L, Vanhorebeek I, Vlasselaers D, *et al*. Intensive insulin therapy protects the endothelium of critically ill patients. *J Clin Invest* 2005; **115**: 2277–86.
93. Vanhorebeek I, De Vos R, Mesotten D, Wouters PJ, Wolf-Peeters C, Van den Berghe G. Protection of hepatocyte mitochondrial ultrastructure and function by strict blood glucose control with insulin in critically ill patients. *Lancet* 2005; **365**: 53–9.
94. Van den Berghe G, Wouters PJ, Bouillon R, *et al*. Outcome benefit of intensive insulin therapy in the critically ill: Insulin dose versus glycemic control. *Crit Care Med* 2003; **31**: 359–66.
95. Van den Berghe G, Wilmer A, Hermans G, *et al*. Intensive insulin therapy in the medical ICU. *N Engl J Med* 2006; **354**: 449–61.

Chapter 4

Pathophysiology of the pneumoperitoneum

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4.1 Introduction

Since the introduction of laparoscopy into mainstream general surgery over 20 years ago, surgeons have witnessed one of the great surgical revolutions. Laparoscopic surgery has changed the approach to many surgical procedures and brought into question the traditional indications of others. Shorter hospital stays and faster recovery times have become the cornerstones upon which laparoscopic instrumentation and skills have justified their existence. Concurrently, the intra-operative and post-operative physiologic effects of laparoscopy, both beneficial and detrimental, have become an important area of research in the ongoing effort to minimize the surgical footprint. The consequential homeostatic alterations to many organ systems that result from laparoscopy are becoming increasingly clear, including cardiovascular, respiratory, renal, hepatic, neurologic, and immunologic. These consequences can be even more profound in MO patients whose physiologic reserve and co-morbid conditions make them more susceptible to the detrimental effects of increased CO_2 as well as the intra-operative increased intra-abdominal pressure (IAP). Increased absorption of CO_2 and the increased IAP during laparoscopy collectively account for the majority of physiologic alterations. It is therefore imperative that the surgeons performing laparoscopy understand these physiologic effects in order to allow for correction of these alterations and minimize their adverse effects.

4.2 Effects of CO_2

In an evolutionary manner, CO_2 has emerged out of helium, oxygen and nitrous oxide as the prevailing gas choice for abdominal insufflation during laparoscopy. It was first proposed in 1926 by Zöllikoffer as a choice for insufflation, but not popularized until 1960 by Kurt Semm upon his development of an automatic insufflation device [1]. Much debate has also occurred with regard to the benefits of abdominal wall lifting during laparoscopy versus gas insufflation, and ultimately pneumoperitoneum with CO_2 has become the approach of choice. Nevertheless, CO_2 has its share of physiologic consequences, including peritoneal and systemic acidification, alterations in cerebral vasoregulation, and systemic vasoconstriction, among others.

4.2.1 Acidification

Pneumoperitoneum with CO_2 gas begins the process of systemic acidification by altering the ultrastructural, metabolic, and immune functions of the peritoneum [1]. The peritoneum is a single continuous layer of mesothelial cells coated with microvilli and joined together by tight junctions. Both animal [2] and human [1] studies confirm CO_2-specific widening of the inter-cellular junctions, and this alteration has been postulated to facilitate systemic acidification via entry of CO_2 into the circulation. In addition, CO_2 insufflation significantly decreases the pH of the peritoneal surface due to accumulation in the parietal peritoneal mesothelial cells [3]. Once this tissue saturation occurs, free hydrogen ions accumulate and then diffuse into the bloodstream [4]. Systemic acidosis, along with hypercapnia, can cause cardiac arrhythmias, vasoconstriction of the pulmonary vasculature, and various alterations in cardiac function. Acidosis due to hypercapnia depresses myocardial contractility, while concurrently stimulating autonomic nervous activity and producing tachycardia and increased cardiac contractility [5]. The net effect can be somewhat variable, but typically heart rate, mean pulmonary artery pressure (PAP), central venous pressure (CVP), systemic vascular resistance (SVR), and mean arterial pressure (MAP) increase,

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while cardiac output (CO) is typically unchanged or decreased and stroke volume is decreased during CO_2 pneumoperitoneum (Table 4.1). Pulmonary artery wedge pressure is typically unchanged [5].

The immune function of the peritoneum is also altered by CO_2 insufflation. West *et al.* demonstrated in an animal model that acidification of the cytoplasm of macrophages along the peritoneum occurs, and corresponds to a reduction of macrophage function [6]. This decreased function is marked by decreased tumor necrosis factor-alpha and interleukin-1 production, and is CO_2-specific. The resultant CO_2-exposed macrophages are unable to generate a normal oxidative burst in response to antigens, and similar results have been shown with CO_2-exposed lymphocytes [7]. Other detrimental effects of CO_2 include decreased macrophage anti-tumor cell cytotoxicity, reduced tumor cell-to-cell adhesion with increased tumor cell detachment, and impaired binding of immune cells to tumor cells [8, 9]. However these detrimental effects are balanced by compelling evidence that the overall systemic immune function is better preserved after laparoscopic surgery [10, 11]. The same suppression of TNF-α production that results from decreased macrophage function appears to also be protective against severe cytokine-induced sepsis. Hanly *et al.* demonstrated that CO_2-specific pneumoperitoneum significantly decreased mortality in lipopolysaccharide-induced animal sepsis [12]. In addition, numerous studies have failed to demonstrate any difference in wound and/or port site metastases between laparoscopic and open cancer surgeries, with port-site metastases occurring less than 1% of the time [11, 13, 14]. What does appear clear is that the overall effect on the immune system resides somewhere in a balance between the local detriments and systemic benefits.

One of the major advantages of CO_2 is its short half life. Wong *et al.* demonstrated a very short CO_2 saturation time of the parietal peritoneum at lower intraperitoneal pressures, due predominately to rapid diffusion into blood with subsequent elimination through the lungs [3]. This characteristic of CO_2 allows for rapid absorption of retained gas after laparoscopy, as well as relative ease of elimination through increased minute ventilation during surgery. In a study of laparoscopic gastric bypass patients, ventilatory adjustments to prevent significant systemic acidosis included increasing respiratory rate by 25% and minute ventilation by 21% intraoperatively [15]. A study by Tan *et al.* in non-obese patients revealed the volume of CO_2 absorbed from the peritoneal cavity ranged from 38 to 42 ml min^{-1} during laparoscopy, representing a 30% increase in the amount of CO_2 relative to pre-insufflation [16]. Nguyen *et al.* also estimated CO_2 absorption during

Table 4.1 Physiologic functional alterations by organ system that occur from pneumoperitoneum

Function	Status
Cardiac/hemodynamic	
Heart rate	Increased
Mean arterial pressure	Increased
Cardiac output	Unchanged/decreased
Stroke volume	Decreased
Systemic vascular resistance	Increased
Mean pulmonary artery pressure	Increased
Pulmonary artery wedge pressure	Unchanged
Central venous pressure	Increased
Visceral blood flow	Decreased
Catecholamine levels	Increased
Respiratory	
Peak inspiratory pressure	Increased
Compliance	Decreased
Tidal volume	Decreased
Physiologic dead space	Increased
PaO_2	Unchanged
Renal	
Intra-operative urine output	Decreased
Post-operative blood urea nitrogen	Decreased
Post-operative creatinine	Decreased
Hepatic	
Intraoperative portal venous flow	Decreased
Post-operative	
AST	Increased
ALT	Increased
Alkaline phosphatase	Decreased
Albumin	Decreased
Total bilirubin	Decreased
Neurologic	
ICP	Increased
O_2 saturation	Decreased
Endocrine	
ADH	Increased
Aldosterone	Increased
Plasma renin	Increased

AST, aspartate aminotransferase; ALT, alanine aminotransferase; ICP, intracranial pressure; ADH, antidiuretic hormone.

laparoscopic gastric bypass to range from 19 to 39 ml min^{-1}, with no significant difference in the absorption and excretion of CO_2 between MO and non-obese subjects [15]. Despite the imperfections of CO_2 as an insufflant, it nevertheless carries the least amount of flammability and post-operative morbidity, as well as the most predictable mode of excretion of the choices currently available.

4.2.2 Alterations in cerebral vasoregulation

Carbon dioxide pneumoperitoneum results in increased intracranial pressure (ICP) through two distinct mechanisms. Increased intrathoracic pressure transmitted through the diaphragm, results in increased CVP and decrease cerebral venous return to the chest and lumbar plexus [17]. In addition and more importantly, systemically absorbed CO_2 vasodilates cerebral arterioles, increasing cerebral blood flow in an autoregulated fashion [18]. The resultant increased ICP decreases cerebral oxygen saturation and initiates a hormonal cascade, which includes catecholamine and vasopressin release that in turn increase systemic vascular resistance. However, the use of sequential compression devices (SCDs) has been shown to counteract the pneumoperitoneum-induced decrease in cerebral oxygenation and restore it to baseline within 35 min of initiation [19]. Sequential compression devices were also shown to significantly lower heart rate (HR), presumably by restoring preload to the heart, which was lost due to IAP slowing venous return. Therefore routine use of SCDs is warranted during laparoscopy.

4.2.3 Cardiovascular effects

Both direct and indirect effects of CO_2 can be seen in numerous aspects of the cardiovascular system (Table 4.1). Carbon dioxide directly decreases myocardial contractility and sensitizes the myocardium to the arrhythmogenic effects of catecholamines [20]. Systemic acidosis also leads to early direct vasodilation of splanchnic blood flow. However, this direct vasodilatory effect is later counteracted by widespread sympathetic stimulation, which results from centrally mediated effects of hypercarbia [20]. This indirect vasoconstriction then becomes the predominate force that ultimately prevails to yield an overall increased vascular resistance. Visceral blood flow, however, has been shown to undergo little change during prolonged pneumoperitoneum. Visceral perfusion initially increases with insufflation, but later returns to baseline within 2 hours of pneumoperitoneum as demonstrated in animal models [21]. However the effects of CO_2 on the cardiovascular system are much less pronounced than the pressure effects of pneumoperitoneum as a whole.

4.3 Increased intra-abdominal pressure

The majority of physiologic changes that occur during pneumoperitoneum stem directly from increased IAP. Virtually every organ system in the body is affected, and each responds predictably, while several have their own compensatory mechanisms. Those organ systems that lack compensatory mechanisms to counterbalance the effects of increased IAP require anesthetic and/or surgical intervention, which the laparoscopic surgeon must be aware of. Both obese and non-obese patients undergo laparoscopy at 15 mm Hg of CO_2 gas in order to provide adequate visualization while minimizing the detrimental effects of increased intra-abdominal pressure. However, obese patient have elevated baseline intra-abdominal pressures of 9–10 mm Hg, nearly double the pressure of non-obese individuals with intra-abdominal pressures of 5 mm Hg or less [22].

4.3.1 Cardiovascular and hemodynamic effects of increased intra-abdominal pressure

The cardiovascular system is the most challenged organ system in the body during laparoscopic surgery, with numerous compensatory mechanisms responding to an overall stress on the system. For example, heart rate and blood pressure both typically increase during laparoscopy [23, 24]. However, some patients may periodically experience vagal-mediated bradycardia due to peritoneal stretching upon insufflation, a phenomenon typically short-lived and relieved with peritoneal desufflation [25]. Most studies evaluating cardiovascular changes with pneumoperitoneum report increased SVR and pulmonary vascular resistances, MAP, right atrial pressure, and pulmonary capillary wedge pressure, while CO is usually reduced [20, 25, 26] (Table 4.1). These changes are further amplified by both IAPs above 15 mm Hg as well as Trendelenburg positioning [27, 28].

Numerous comparisons have also evaluated the effects of pneumoperitoneum in various groups of patients. Fried *et al.* compared obese and non-obese subjects and found that heart rate increased after pneumoperitoneum in both groups, but that obese

individuals had a more pronounced increase in heart rate [29]. There was also a 12% increase in CO in the MO subjects after abdominal insufflation, which was not seen in the non-obese subjects. Other authors have examined the cardiovascular effects after insufflation compared to those after abdominal wall lifting and found pneumoperitoneum to be the responsible factor for the vast majority of changes seen during laparoscopy [30]. Nguyen *et al.* found 6% and 8% decreases in CO and stroke volume, respectively, with abdominal insufflation in MO subjects as measured by Swan–Ganz catheter [31]. However, obese subjects, in contrast to non-obese subjects, demonstrated minimal cardiac depression. The authors thus hypothesized that obese subjects are better equipped to compensate for increased intra-abdominal pressure due to the higher baseline pressures of 9–10mm Hg relative to that of less than 5mm Hg in non-obese subjects. Studies in non-obese patients by Westerband *et al.* [32] and McLaughlin *et al.* [33] both found a nearly 30% reduction in cardiac index in non-obese patients who underwent laparoscopic cholecystectomy. These findings also support the notion that obese subjects already have compensatory mechanisms in place that minimize the impact of pneumoperitoneum on the cardiovascular system.

4.3.2 Respiratory effects

Although there are numerous etiologies of cardiovascular changes during pneumoperitoneum, respiratory changes can be almost entirely attributed to mechanical pressure transmitted through the diaphragm resulting in increased intrathoracic pressure. This pressure in turn decreases lung volumes, including vital capacity and functional residual capacity, and decreases pulmonary compliance (Table 4.1). Physiologic dead space is increased, resulting in a greater ventilation-perfusion mismatch [25]. These alterations rarely become clinically significant in patients with normal pre-operative pulmonary function. However, patients with chronic obstructive pulmonary disease (COPD) with impaired compensatory mechanisms are at high risk for developing hypoxemia and significant hypercapnia. In obese patients undergoing laparoscopic surgery, pulmonary compliance decreases by 42%, compared to a 29% decrease during open bariatric surgery [15].

Increases in airway pressures also occur during laparoscopy and may require ventilatory manipulation. Uncompensated peak inspiratory pressures (PIP) can increase by 17–109% during laparoscopic surgery in non-obese patients, depending on the study [5]. However, obese subjects tend to have less pronounced changes. Nguyen *et al.* found a 12% increase in PIP during laparoscopic gastric bypass [15], while Dumont *et al.* reported a 17% increase in PIP during laparoscopic gastroplasty [34]. Studies in patients that underwent abdominal wall lifting instead of pneumoperitoneum confirmed these increases in PIP to be attributed to the pressure effects of abdominal insufflation [5]. Recent data from high-risk patients randomized to pneumoperitoneum vs. abdominal wall lifting showed that laparoscopic surgery is safe even in high anesthetic risk patients provided that appropriate pre-operative fluid loading, and intraoperative monitoring and ventilatory adjustments take place [35]. This monitoring included end-tidal CO_2 ($ETCO_2$) and urine output.

Despite the alterations in pulmonary compliance and increases in airway pressures, the exchange of gases across the lung is generally unaffected by laparoscopy [16]. Numerous studies have demonstrated no significant changes in alveolar-arterial oxygen gradient in MO patients undergoing laparoscopic bariatric surgery [15, 36]. Demiroluk *et al.* also reported no differences in arterial partial pressure of oxygen (PaO_2) between MO and non-obese patients [37]. However when Trendelenburg positioning was added to pneumoperitoneum, even overweight patients have been shown to have significantly impaired PaO_2 as well as alveolar–arterial differences in oxygen tension (A_aDO_2) [38]. In both obese and non-obese patients pneumoperitoneum alone during laparoscopy is well tolerated, but caution must be exercised when adding other pulmonary co-morbidities and/or patient positioning that further impair normal respiratory physiology.

4.3.3 Renal effects

An overall decrease in renal perfusion and a resultant increase in hormonal activity occur with pneumoperitoneum. Several mechanisms account for decreased urine output during laparoscopy, including the direct pressure effect of pneumoperitoneum and increased IAP on renal blood flow. Chiu *et al.* reported renal cortical blood flow decreased by as much as 60% during insufflation but returned to normal with desufflation [39]. Animal studies have demonstrated a decreased renal blood flow by 36% below baseline, as well as increased release of antidiuretic hormone (ADH), plasma renin activity, and serum aldosterone during pneumoperitoneum [25,40]. These hormones collectively promote water retention through concentration

of sodium and water, decreasing urine output in a rapid fashion. These same hormone levels were shown to significantly increase in MO patients undergoing laparoscopic gastric bypass [41] as well as non-obese patients undergoing laparoscopic cholecystectomy, but remained normal in patients undergoing open cholecystectomy [42]. Despite these hormonal changes and a transient oliguria, clinically significant renal impairment as measured by serum creatinine did not occur after laparoscopic gastric bypass nor adrenalectomy compared to open procedures [41, 43]. Yet caution must be exercised and close monitoring instituted in patients with significantly impaired pre-operative renal function to avoid further exacerbation of the condition.

The extent of intraoperative oliguria is directly related to the extent of increased IAP. McDougall *et al.* demonstrated this correlation in a swine model, with higher pressures yielding correspondingly greater oliguria [44]. Similar findings were revealed in a study of critically ill patients where IAPs greater than 25 mm Hg resulted in acute renal insufficiency, with immediate improvement upon decompression [45]. Similar to non-obese subjects, MO patients demonstrated an immediate decrease in urine output after initiation of pneumoperitoneum during laparoscopic gastric bypass and remained between 31% and 64% lower during insufflation compared to patients during open gastric bypass [41]. These findings reinforce the importance of utilizing minimal insufflation pressure during laparoscopy, particularly in those patients with pre-existing renal impairment pre-operatively.

4.3.4 Hepatic effects

Overall effects of pneumoperitoneum on hepatic blood flow and function are similar to those of the kidneys. Both animal and human studies by Jakimowics and colleagues have demonstrated that intra-abdominal pressures of 15mm Hg reduce portal venous flow, by as much as 53% [46]. This decrease in blood flow which provides 75% of the supply to the liver can lead to hepatic hypoperfusion, acute hepatocelluar injury, and transient elevation of liver enzymes. These elevations have been demonstrated after cholecystectomy, but tend to normalize within 72 hours [47]. Similar studies in MO patients have shown some transaminase levels rising as much as six-fold and peaking 24 hours after surgery, but also returning to baseline by the third post-operative day [48]. These alterations are even more important in MO patients who often have underlying hepatic disease, rates of which can be as high as 84% [49]. Other mechanisms besides reduced portal flow from pneumoperitoneum include operative trauma, typically from liver retraction during laparoscopic foregut surgery, and general anesthetic agents. Normal portal pressure is less than 10mm Hg, allowing for intra-abdominal pressure above that level to potentially impair portal flow. However, pneumoperitoneum, even in MO subjects, is still considered safe provided that intra-abdominal pressures do not exceed 15mmHg, operative trauma is minimized, and appropriate anesthetic precautions are taken in those patients who have known underlying hepatic disease.

4.3.5 Effects on regional blood flow

Increased intra-abdominal pressure has detrimental effects on both the venous drainage of the lower extremities, as well as the visceral blood flow similar to the effects previously described on renal and hepatic function (Table 4.2). Numerous studies have demonstrated reduced femoral venous flow during laparoscopy [50, 51]. This impediment to venous flow stems from direct pressure on the iliac veins and inferior vena cava (IVC), and is further exacerbated by gravity when reverse Trendelenburg positioning is utilized. Additional pressure may also stem from abdominal viscera compressing the IVC and iliac veins during this position. Reverse Trendelenburg (30°) position, in combination with pneumoperitoneum has been shown to decrease peak systolic velocity of the common femoral veins by 42% [50]. Nguyen *et al.* revealed in a study of laparoscopic and open gastric bypass patients that increased IAP and reverse Trendelenburg positioning are independent factors in decreasing peak femoral systolic velocity [52]. Increased IAP during laparoscopic bariatric surgery also increased femoral cross-sectional area by 52%. When both pneumoperitoneum and reverse Trendelenburg positioning were combined, the additive effect created a peak femoral systolic velocity that was reduced by 57% below baseline values [52]. It then becomes clear that MO patients are at high risk for developing deep venous thrombosis (DVT) peri-operatively from venous stasis, and preventative measures are mandatory to temper such risk.

Splanchnic circulation may also be impaired during periods of increased intra-abdominal pressure. Using a laser Doppler, Schilling *et al.* reported in 18 patients that increasing IAP from 10 mm Hg to 15 mm Hg significantly decreased blood flow to the stomach, duodenum, jejunum, colon, liver, and parietal

Table 4.2 Effects of 15 mm Hg CO_2 pneumoperitoneum on regional blood flow

Region	Effect
Lower extremities	
Femoral peak systolic velocity	↓↓43%
Femoral cross-sectional area	↑↑52%
Abdominal viscera	
Stomach	↓↓54%
Duodenum	↓↓11%
Jejunum	↓↓32%
Colon	↓↓44%
Liver	↓↓39%
Parietal peritoneum	↓↓60%

peritoneum [53]. In addition, splanchnic blood flow was also shown to decrease with insufflation time given a constant arterial pressure. Postulated mechanisms include compression of the superior mesenteric artery and portal vein. While a moderate amount of animal data exist to confirm the detrimental effects of rising IAP on splanchnic circulation, very little animal or human data exist to substantiate the clinical translation of these findings. As a result, IAP of 15mm Hg is typically used in most laparoscopic settings with very little evidence to support meaningful or lasting harm to abdominal viscera in humans.

4.4 Intraoperative management

Effective preventions or control of detrimental effects of CO_2 pneumoperitoneum are key to maintaining the safety profile of laparoscopy. Numerous principles of laparoscopic surgery have evolved to facilitate both anesthesiologists and surgeons in achieving safe outcomes.

4.4.1 Ventilatory changes

Appropriate ventilatory adjustments can eliminate most of the direct detrimental effects of CO_2 and prevent acid-base disturbances. These changes are summed up by increasing minute ventilation. Several studies in bariatric patients undergoing laparoscopic gastroplasty or gastric bypass have validated an increase in minute ventilation by 21% to prevent acidosis [15, 34]. This increased ventilation is most often achieved by augmenting the respiratory rate by 25%, which facilitates the elimination rate of increased CO_2 load produced by peritoneal absorption. By increasing respiratory rate and lowering tidal volumes, PIPs are minimized in the setting of increased intrathoracic pressures which stem from increased IAP. A reasonable goal for minute volume should be 12–15ml kg^{-1}, with subsequent alterations to account for patient co-morbidities such as COPD or volume status [25]. While positive end expiratory pressure (PEEP) can improve gas exchange, it also substantially increases intrathoracic pressure in the setting of increased IAP and results in further depression of CO. Therefore, PEEP must be used judiciously and is often implemented at 5 cm H_20 to minimize its detriment [20].

4.4.2 Patient positioning

Trendelenburg position contributes to increasing intrathoracic pressure through several mechanisms. First, abdominal viscera in combination with pneumoperitoneum and increased IAP transmit cephalad pressure on the diaphragm and directly increase intra-thoracic pressure. This pressure decreases lung compliance and subsequently lung function. Additionally, increased venous return from the abdomen and lower extremities due to gravity will increase intra-thoracic blood flow, further contributing to increased intra-thoracic pressure. Reverse Trendelenburg, on the other hand, will further exacerbate venous stasis in the lower extremities in the presence of pneumoperitoneum. This position also diminishes venous return to the heart. When combined with an increased afterload due to elevated IAP, reverse Trendelenburg position can result in substantial decreases in CO. As both patient positions have their respective detriments, avoiding prolonged periods of either extreme of position can minimize the clinical sequelae.

4.4.3 Minimizing intra-abdominal pressure

As the exact IAP to minimize the harmful effects of pneumoperitoneum while maximizing visualization is not known, the approach to each patient should be individualized. Patients with COPD will often require lower IAP during laparoscopy. Conversely, MO patients will not only tolerate a greater pressure due to the higher baseline IAP, but may often require higher pressures to allow for adequate visualization of the operative field. An overriding principle that most authors advocate is to minimize the IAP whenever possible [25].

4.4.4 Optimize volume status

Numerous factors affect cardiac function, including heart rate, contractility, preload, afterload, and cardiac compliance. Euvolemia through pre-operative loading

of fluids can minimize the effects of pneumoperitoneum on preload and counterbalance the increased thoracic pressure transmitted through the diaphragm to the cardiac chambers, and hence minimize intraoperative cardiac depression. Intravenous fluid (IVF) loading can also minimize the decrease in CVP and PAP, which can contribute to impaired cardiac performance. Demyttenaere *et al*. found that aggressive fluid hydration during pneumoperitoneum at 15 mm Hg preserved CO, stroke volume, and renal cortical perfusion while increasing urine output [54]. A meta-analysis by the same authors confirmed improved renal blood flow with fluid hydration [55]. Finally, Junghans *et al*. found increased intrathoracic blood volume through IVF loading significantly improved hemodynamic function in all patient positions [26]. Pre-operative hydration appears critical to minimizing most of the negative effects of pneumoperitoneum during laparoscopy.

4.4.5 Use of sequential compression devices

Routine use of SCDs provides numerous benefits. Bickel *et al*. evaluated 22 patients with at least 10% reduction in CO after induction of pneumoperitoneum and found significant improvement in CO, stroke volume, portal venous and hepatic arterial blood flow, and marked improvement in renal perfusion, urine output, and systemic vascular resistance with use of SCDs intra-operatively [56]. While the risk of venous thromboembolism is higher in laparoscopic patients due to increased IAP, particularly in obese patients, the overall incidence is lower than with open surgery [57]. Nevertheless, with the numerous benefits that stem from SCDs, their routine use has become widely recommended for all laparoscopic surgery.

References

1. Neuhaus SJ, Watson DI. Pneumoperitoneum and peritoneal surface changes. *Surg Endosc* 2004; **18**: 1316–1322.
2. Rosario MT, Ribeiro U Jr, Corbett CE, *et al*. Does CO_2 pneumoperitoneum alter the ultra-structure of the mesothelium? *J Surg Res* 2006; **133**: 84–8.
3. Wong YT, Shah PC, Birkett DH, Brams DM. Peritoneal pH during laparoscopy is dependent on ambient gas environment: helium and nitrous oxide to not cause peritoneal acidosis. *Surg Endosc* 2005; **19**: 60–4.
4. Mynbaev OA, Dolle L, Brack M. A possible mechanism of peritoneal pH changes during carbon dioxide pneumoperitoneum. *Surg Endosc* 2007; **21**: 489–91.
5. Nguyen NT, Wolfe BM. The physiologic effects of pneumoperitoneum in the morbidly obese. *Ann Surg* 2005; **241**: 219–26.
6. West MA, Hackman DJ, Baker J, Rodriguez JL, Bellingham J, Rotstein OD. Mechanism of decreased in vitro murine macrophage cytokine release after exposure to carbon dioxide: relevance to laparoscopic surgery. *Ann Surg* 1997; **226**: 179–90.
7. Evrard S, Falkenrodgt A, Park A, Tassetti V, Mutter D, Marescasux J. Influence of CO_2 pneumoperitoneum on systemic and peritoneal cell-mediated immunity. *World J Surg* 1997; **21**: 353–6.
8. Puttick MI, Nduka CC, Yong LY, Darzi A. Exposure of peritoneal macrophages to carbon dioxide pneumoperitoneum suppresses function and diminishes antitumour cell cytotoxicity. *Br J Surg* 1998; **85**: 1579.
9. Nduka CC, Coates P, Poland N, *et al*. Intraoperative modulation of the metastatic cascade by carbon dioxide pneumoperitoneum. *Br J Surg* 1997; **84**: 1613–14.
10. Allendorf JF, Bessler M, Horvath KD, Marvin MR, Laird DA, Whelan RL. Increased tumor establishment and growth after open vs laparoscopic surgery in mice may be related to differences in postoperative T-cell function. *Surg Endosc* 1999; **13**: 233–5.
11. Schwenk W, Jacobi C, Mansmann U, Bohm B, Muller JM. Inflammatory response after laparoscopic and conventional colorectal resections: results of a prospective randomized trial. *Langenbecks Arch Surg* 2000; **385**: 2–9.
12. Hanly EJ, Fuentes JM, Aurora AR, *et al*. Carbon dioxide pneumoperitoneum prevents mortality from sepsis. *Surg Endosc* 2006; **20**: 1482–7.
13. Hazebroek EJ, Color Study Group. COLOR: a randomized clinical trial comparing laparoscopic and open resection for colon cancer. *Surg Endosc* 2002; **16**: 949–53.
14. Chapman AE, Levitt MD, Hewett P, Woods R, Sheiner H, Maddern GJ. Laparoscopic-assisted resection of colorectal malignancies: a systemic review. *Ann Surg* 2001; **234**: 590–606.
15. Nguyen NT, Anderson J, Budd M, Fleming NW, *et al*. Effects of pneumoperitoneum on intraoperative respiratory mechanics and gas exchange during laparoscopic gastric bypass. *Surg Endosc* 2004; **18**: 64–71.
16. Tan PL, Lee TL, Tweed WA. Carbon dioxide absorption and gas exchange during pelvic laparoscopy. *Can J Anaesth* 1992; **39**: 677–81.
17. Schob OM, Allen DC, Benzel E, *et al*. A comparison of the pathophysiologic effects of carbon dioxide, nitrous oxide, and helium pneumoperitoneum on intracranial pressure. *Am J Surg* 1996; **172**: 248–53.
18. Cooke SJ, Paterson-Brown S. Association between laparoscopic abdominal surgery and postoperative

symptoms of raised intracranial pressure. *Surg Endosc* 2001; **15**: 723–5.

19. Kurukahvecioglu O, Sare M, Karamercan A, Gunaydin B, Anadol Z, Tezel E. Intermittent pneumatic sequential compression of the lower extremities restores the cerebral oxygen saturation during laparoscopic cholecystectomy. *Surg Endosc* 2008; **22**: 907–11.
20. Gutt CN, Oniu T, Mehrabi A, *et al*. Circulatory and respiratory complications of carbon dioxide insufflation. *Dig Surg* 2004; **21**: 95–105.
21. Goitein D, Papasavas P, Yeaney W, *et al*. Microsphere intestinal blood flow analysis during pneumoperitoneum using carbon dioxide and helium. *Surg Endosc* 2005; **19**: 541–5.
22. Nguyen NT, Lee SL, Anderson JT, Palmer LS, Canet F, Wolfe BM. Evaluation of intra-abdominal pressure after laparoscopic and open gastric bypass. *Obes Surg* 2001; **11**: 40–5.
23. Dexter SP, Vucevic M, Gibson J, McMahon MJ. Hemodynamic consequences of high- and low-pressure capnoperitoneum during laparoscopic cholecystectomy. *Surg Endosc* 1999; **13**: 376–81.
24. Meininger D, Byhahn C, Bueck M, *et al*. Effects of prolonged pneumoperitoneum on hemodynamics and acid-base balance during totally endoscopic robot-assisted radical prostatectomies. *World J Surg* 2002; **26**: 1423–7.
25. Henny CP, Hofland J. Laparoscopic surgery – pitfalls due to anesthesia, positioning, and pneumoperitoneum. *Surg Endosc* 2005; **19**: 1163–71.
26. Junghans T, Modersohn D, Dörner F, Neudecker J, Haase O, Schwenk W. Systematic evaluation of different approaches for minimizing hemodynamic changes during pneumoperitoneum. *Surg Endosc* 2006; **20**: 763–9.
27. Hirvonen EA, Nuutinen LS, Kauko M. Hemodynamic changes due to Trendelenburg positioning and pneumoperitoneum during laparoscopic hysterectomy. *Acta Anaesthesiol Scand* 1995; **39**: 949–55.
28. Falabella A, Moore-Jeffries E, Sullivan MJ, Nelson R, Lew M. Cardiac function during steep Trendelenburg position and CO_2 pneumoperitoneum for robotic-assisted prostatectomy: a trans-oesophageal Doppler probe study. *Int J Med Robot* 2007; **3**: 312–5.
29. Fried M, Krska Z, Danzig V. Does the laparoscopic approach significantly affect cardiac functions in laparoscopic surgery? Pilot study in non-obese and morbidly obese patients. *Obes Surg* 2001; **11**: 293–6.
30. Ninomiya K, Kitano S, Yoshida T, Bandoh T, Baatar D, Matsumoto T. Comparison of pneumoperitoneum and abdominal wall lifting as to hemodynamics and surgical stress response during laparoscopic cholecystectomy. *Surg Endosc* 1998; **12**: 124–8.
31. Nguyen NT, Ho HS, Fleming NW, *et al*. Cardiac function during laparoscopic vs open gastric bypass. *Surg Endosc* 2002; **16**: 78–83.
32. Westerband A, Van De Water JM, Amzallag M, *et al*. Cardiovascular changes during laparoscopic cholecystectomy. *Surg Gynecol Obstet* 1992; **175**: 535–8.
33. McLaughlin JG, Scheeres DE, Dean RJ, Bonnell BW. The adverse hemodynamic effects of laparoscopic cholecystectomy. *Surg Endosc* 1995; **9**: 121–4.
34. Dumont L, Mattys M, Mardirosoff C, Vervloesem N, Alle JL, Massaut J. Changes in pulmonary mechanics during laparoscopic gastroplasty in the morbidly obese patient. *Acta Anaesthesiol Scand* 1997; **41**: 408–13.
35. Koivusalo AM, Pere P, Valjus M, Scheinin T. Laparoscopic cholecystectomy with carbon dioxide pneumoperitoneum is safe even for high-risk patients. *Surg Endosc* 2008; **22**: 61–7.
36. Sprung J, Whalley DG, Falcone T, Wilks W, Navratil JE, Bourke DL. The effects of tidal volume and respiratory rate on oxygenation and respiratory mechanics during laparoscopy in morbidly obese patients. *Anesth Analg* 2003; **97**: 268–74.
37. Demiroluk S, Salihoglu Z, Zengin K, Kose Y, Taskin M. The effects of pneumoperitoneum on respiratory mechanics during bariatric surgery. *Obes Surg* 2002; **12**: 376–9.
38. Meininger D, Zwissler B, Byhahn C, Probst M, Westphal K, Bremerich DH. Impact of overweight and pneumoperitoneum on hemodynamics and oxygenation during prolonged laparoscopic surgery. *World J Surg* 2006; **30**: 520–6.
39. Chiu AW, Chang LS, Birkett DH, Babayan RK. The impact of pneumoperitoneum, pneumoretroperitoneum, and gasless laparoscopy on the systemic and renal hemodynamics. *J Am Coll Surg* 1995; **181**: 397–406.
40. Are C, Kutka M, Talamini M, *et al*. Effect of laparoscopic antireflux surgery upon renal blood flow. *Am J Surg* 2002; **183**: 419–23.
41. Nguyen NT, Perez RV, Fleming N, Rivers R, Wolfe BM. Effect of prolonged pneumoperitoneum on intraoperative urine output during laparoscopic gastric bypass. *J Am Coll Surg* 2002; **195**: 476–83.
42. Ortega AE, Peters JH, Incarbone R, *et al*. A prospective randomized comparison of the metabolic and stress hormonal responses of laparoscopic and open cholecystectomy. *J Am Coll Surg* 1996; **183**: 249–56.
43. Nishio S, Takeda H, Yokoyama M. Changes in urinary output during laparoscopic adrenalectomy. *Br J Urol Intl* 1999; **83**: 944–7.
44. McDougall EM, Monk TG, Wolf JS Jr, *et al*. The effect of prolonged pneumoperitoneum on renal function in an animal model. *J Am Coll Surg* 1996; **182**: 317–28.

45. Kron IL, Harman PK, Nolan SP. The measurement of intra-abdominal pressure as a criterion for abdominal re-exploration. *Ann Surg* 1984; **199**: 28–30
46. Jakimowics J, Stultiens G, Smulders F. Laparoscopic insufflation of the abdomen reduces portal venous flow. *Surg Endosc* 1998; **12**: 129–32.
47. Halevy A, Gold-Deutch R, Negri M, *et al*. Are elevated liver enzymes and bilirubin levels significant after laparoscopic cholecystectomy in the absence of bile duct injury? *Ann Surg* 1994; **219**: 362–4.
48. Nguyen NT, Braley S, Fleming NW, Lambourne L, Rivers R, Wolfe BM. Comparison of postoperative hepatic function after laparoscopic versus open gastric bypass. *Am J Surg* 2003; **186**: 40–4.
49. Gholam PM, Kotler DP, Flancbaum LJ. Liver pathology in morbidly obese patients undergoing Roux-en-Y gastric bypass surgery. *Obes Surg* 2002; **12**: 49–51.
50. Millard JA, Hill BB, Cook PS, Fenoglio ME, Stahlgren LH. Intermittent sequential pneumatic compression in prevention of venous stasis associated with pneumoperitoneum during laparoscopic cholecystectomy. *Arch Surg* 1993; **128**: 914–9.
51. Ido K, Suzuki T, Kimura K, *et al*. Lower-extremity venous stasis during laparoscopic cholecystectomy as assessed using color Doppler ultrasound. *Surg Endosc* 1995; **9**: 310–3.
52. Nguyen NT, Cronan M, Braley S, Rivers R, Wolfe BM. Duplex ultrasound assessment of femoral venous flow during laparoscopic and open gastric bypass. *Surg Endosc* 2003; **17**: 185–90.
53. Schilling MK, Redaelli C, Krahenbuhl L, Signer C, Buchler MW. Splanchnic microcirculatory changes during CO_2 laparoscopy. *J Am Coll Surg* 1997; **184**: 378–82.
54. Demyttenaere SV, Feldman LS, Bergman S, *et al*. Does aggressive hydration reverse the effects of pneumoperitoneum on renal perfusion? *Surg Endosc* 2006; **20**: 274–80.
55. Demyttenaere S, Feldman LS, Fried GM. *Surg Endosc* 2007; **21**: 152–60
56. Bickel A, Loberant N, Bersudsky M, *et al*. Overcoming reduced hepatic and renal perfusion caused by positive-pressure pneumoperitoneum. *Arch Surg* 2007; **142**: 119–24.
57. Nguyen NT, Hinojosa MW, Fayad C, *et al*. Laparoscopic surgery is associated with a lower incidence of venous thromboembolism compared with open surgery. *Ann Surg* 2007; **246**: 1021–7.

Section 2
Chapter
5

Preparation and pre-operative evaluation/ management
Choice of bariatric operation

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5.1 Introduction

The unchecked growth of obesity around the world continues to plague the healthcare community. The World Health Organization estimates one out of six people worldwide, roughly 1 billion people, is overweight. Approximately 97 million Americans are overweight and 23 million are morbidly obese [1]. The epidemic also includes the adolescent and pediatric populations, rising at a similar rate to adults. Obesity is estimated to result in more than 300 000 deaths in the USA per year. This is second only to smoking as a cause for preventable death [2]. The costs of caring for the obese is staggering. It is currently over $200 billion yearly in the USA and will certainly increase in the next decade. Unfortunately, non-surgical weight loss remedies that yield meaningful and sustained weight loss still do not exist. Therefore, it is not a surprise that the field of bariatric surgery has significantly expanded from its modest beginnings in the 1950s. A number of different operative procedures have been developed. Some have been abandoned, some have evolved into safer and more efficacious variants, and newer procedures continue to be adopted.

At present, there are four main types of operative procedures being performed worldwide. These are the laparoscopic adjustable gastric band, Roux-en-Y gastric bypass, the biliopancreatic diversion (the Scopinaro version or the duodenal switch variant), and a relatively new procedure, the gastric sleeve resection. Unfortunately there is no gold standard bariatric procedure that should be offered to all potential candidates. Each of the above-mentioned procedures are capable of achieving meaningful and sustainable weight loss, improving co-morbid conditions, increasing life expectancy, and improving quality of life [3–5]. However, the response each patient may have to a particular procedure is not predictable. Some patients succeed greatly while others less so, and some patients are totally non-responsive. The etiology for this phenomenon is likely multifactorial. Firstly, these operations are anatomically and physiologically distinct from one another. Secondly, the MO population undergoing consideration for surgery is an extremely heterogeneous group in regard to degree of adiposity, presence and severity of co-morbid conditions, eating habits, psychologic behavior, socioeconomic standings, education, intelligence, and even physiology. Therefore, it is impractical to assume that any one bariatric procedure would succeed in all patients.

Maximizing success and minimizing poor outcomes should be the goal of every bariatric surgical program. Matching a patient with a procedure most likely to succeed is therefore a very attractive concept. However, can that be accomplished? To date there is little published information to improve patient selection. This chapter will review the factors involved in deciding which operation to perform for an operative candidate.

5.2 Operative choices

The four different bariatric surgical procedures now being performed have the potential to succeed in achieving meaningful and sustainable weight loss and improve the health and well-being of the patient. They each differ in design, mechanism(s) of action, outcomes, and potential long-term consequences.

5.2.1 Adjustable gastric band

In this procedure an adjustable silicone band is placed around the upper stomach creating a 15–20 ml pouch; thereby limiting food intake [6] (Figure 5.1). As much as 40–60% of excess weight can be lost with the gastric band [7, 8]. As the method of weight loss is purely restrictive, there is little concern for anemia and

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

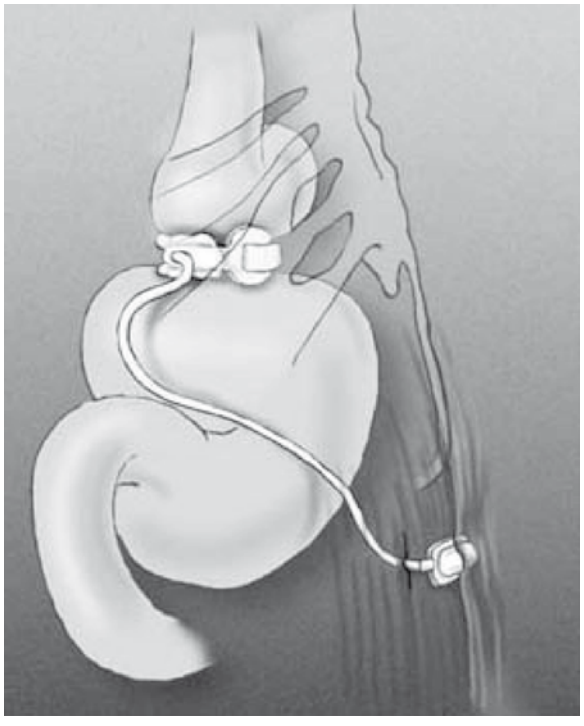

Figure 5.1 Laparoscopic adjustable gastric band.

vitamin deficiencies that is seen with some of the other bariatric procedures. Thirty-day mortality is 0.1% [7, 9]. The common complications reported include band slippage, erosion into the stomach or pouch dilatation. The risk of band erosion is 1–2% while the risk for slippage is 2–4% [7].

5.2.2 Roux-en-y gastric bypass

This is the most common weight loss procedure performed in the United States and is a mixed restrictive and malabsorptive procedure. The stomach is divided so that a 15–30 ml pouch is created. The rest of the stomach is excluded from the alimentary tract. The pouch is connected to the jejunum via a Roux-en-Y gastrojejunostomy (Figure 5.2). Patients can lose more than 50% of their excess weight [10–12]. The operative mortality ranges from 0.3% to 1.6% [12–14]. Thirty-day mortality is less than 1% [11]. Serious complications include deep venous thrombosis, pulmonary embolism, and gastrointestinal leak. Long-term complications can include anemia, vitamin and mineral deficiencies. Serum levels of iron, folate, and vitamin B_{12} should be monitored closely as many patients require lifelong supplementation [15–18].

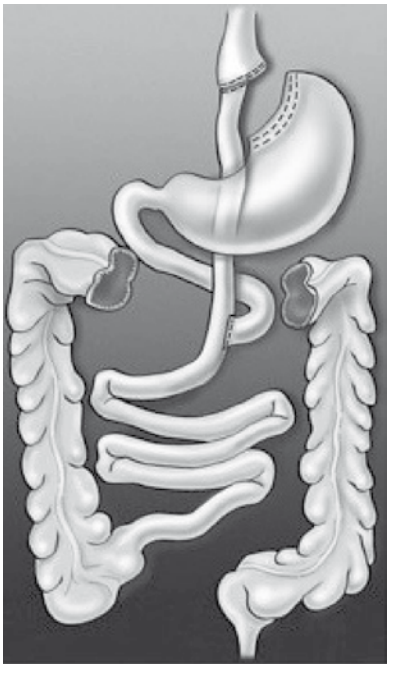

Figure 5.2 Roux-en-y gastric bypass.

5.2.3 Biliopancreatic diversion

This operation is predominantly malabsorptive and results in far more malabsorption than the gastric bypass operation. It involves a partial gastrectomy with the gastric remnant anastomosed to the distal ileum. The proximal ileum is anastomosed to the terminal ileum, creating a common channel approximately 50–100 cm from the ileocecal valve (Figure 5.3). Nutrient absorption only occurs in this common channel as this is the first place along the intestinal tract that food is mixed with bile and digestive enzymes. The partial gastrectomy is thought to initiate weight loss by limiting food intake while the intestinal bypass is thought to maintain weight loss secondary to malabsorption. Excess weight loss has been reported as high as 72% [19]. The operative 30-day mortality for biliopancreatic diversion is 1.1% [3]. The most serious complications include malnutrition and severe vitamin deficiency, which can be limited by extending the length of the common channel [20].

A variant of the biliopancreatic diversion, biliopancreatic diversion with duodenal switch (Figure 5.4), leaves the first part of the duodenum intact thereby decreasing the incidence of stomal ulceration and dumping [20]. This procedure involves a sleeve gastrectomy leaving intact the antrum, pylorus, and first part of the duodenum. The distal ileum is anastomosed

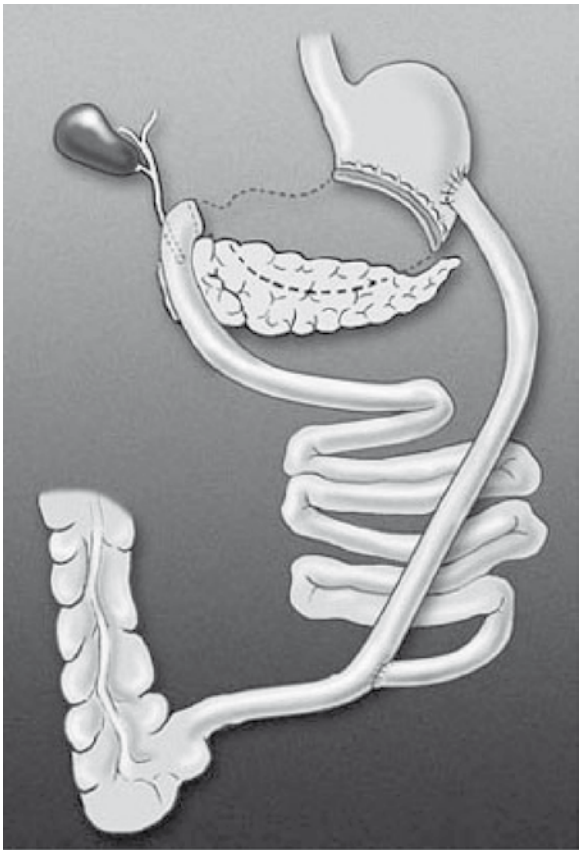

Figure 5.3 Biliopancreatic diversion.

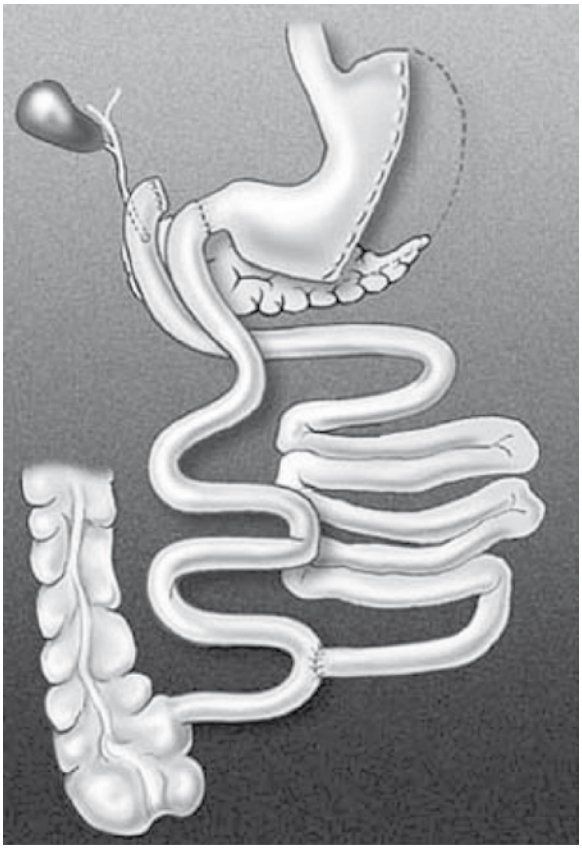

Figure 5.4 Biliopancreatic diversion with duodenal switch.

to the duodenum while the proximal ileum is anastomosed to the terminal ileum, creating a common channel approximately 50 to 100 cm from the ileocecal valve. Long-term follow-up with vitamin and protein surveillance is critical.

5.2.4 Sleeve gastrectomy

In this procedure the greater curvature of the stomach is excised leaving a tubular section along the lesser curvature (Figure 5.5). This leads to early satiety and decreased appetite as a result of gastric restriction. Excess weight loss averages 40% to 50% [21, 22]. The procedure was initially introduced as the first part of a two-staged approach for high-risk patients [23]. The sleeve procedure would be performed first and would achieve a degree of weight loss. The patient would then undergo a second procedure such as a Roux-en-Y gastric bypass or duodenal switch. However, some patients opted not to undergo the second procedure, as they were so pleased with the results of the sleeve gastrectomy. This led to the interest in the sleeve as a primary procedure [24]. A growing body of literature has shown the sleeve to be somewhere between the band and the bypass in terms of complications and results. Although the sleeve is currently enjoying increasing popularity among surgeons and patients, there are only a few publications with results beyond 5 years. In addition, there is concern that the remaining stomach may dilate with time resulting in weight loss failure necessitating a second bariatric procedure such as the adjustable gastric band, gastric bypass, or biliopancreatic diversion [25].

5.3 Matching patient to procedure or procedure to patient

In a perfect world, potential surgical candidates would be evaluated, assessed, and then assigned to the operative procedure that would most likely match their characteristics resulting in the best outcomes. This assignment would be performed by a validated system, algorithm, or computer generated statistical analysis. Unfortunately, our world is not perfect and currently

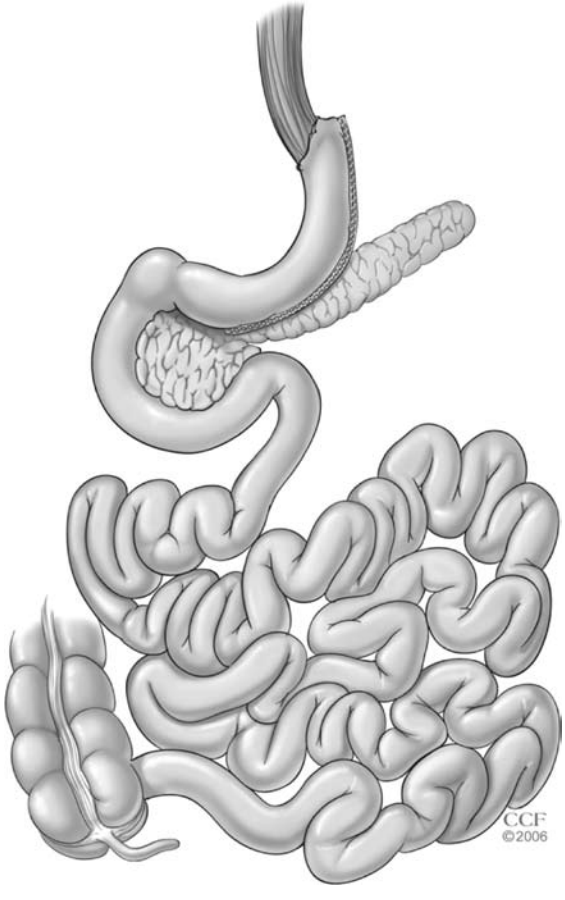

Figure 5.5 Sleeve gastrectomy. Reproduced with permission: Philip Schauer, MD, Cleveland Clinic Foundation).

BMI	• 35-39.9 • 40-44.9 • 45-49.9 • 50-54.9 • > 50	2 points 3 points 4 points 5 points 6 points
Age	• < 40 • > 40	– 0.5 points + 0.5 points
Gender, race, body habitus Pear vs. android Central obesity	• Favorable • Unfavorable	– 0.5 points + 0.5 points
Significant pre-operative co-morbidities	• Low number • High number	– 1 point + 1 point

Figure 5.6 Bariatric point system: A point system was proposed to assist in choosing the most appropriate operative procedure for a given patient. Patient characteristics were assigned numeric values. A patient score can then be calculated from the following equation: Operative choice = 1.0 + BMI number + 0.5 age + 0.5 gender/race/body habitus + co-morbiditiesThe patient score can then be used to pick the most appropriate procedure (see Figure 5.7).

Figure 5.7 Bariatric surgical options: Based on the patient score, the "most appropriate" operative procedure can be selected for every patient. GB, gastric band; VBG, vertical banded gastroplasty; RYGB, Roux-en-Y gastric bypass; BPD ± DS, biliopancreatic diversion, duodenal switch; Long limb RYGB, long limb Roux-en-Y gastric bypass, common channel is approximately 100 cm. Adapted from: Ref [26] .

no such system exists. Whether this is due to the heterogeneity of the disease or the unpredictable influence of a patient's behavior, societal setting, or environmental influences is currently not clear.

An attempt to create such an algorithm was undertaken by Buchwald in 2002 [26]. Based on a literature review of 54 papers, patient, procedure, and outcomes variables were analyzed in an attempt to "determine the most suitable operation for a given patient." These variables included patient variables (BMI, age, gender, race, body habitus, and presence of major co-morbidities), outcomes variables (weight loss, procedure complications, resolution of co-morbid conditions, and patient satisfaction), operative variables (type of procedure), and some hypothetic criteria and suppositions. Points were then assigned to each category (Figure 5.6). The total number of points proposes suitable operative options (Figure 5.7). Unfortunately, this algorithm was not scientifically derived or clinically validated. In essence, it steers younger and healthier patients to less radical procedures such as the gastric band, while heavier and more complicated patients are directed to more radical procedures such as the biliopancreatic diversion or long-limb Roux-en-Y gastric bypass. This algorithm at best only guides a discussion between the surgeon and the patient.

There are many factors that must be considered when discussing surgical options with a bariatric surgical candidate (Table 5.1). In some cases, patients will be offered a choice of several operative procedures and in other cases the choice may be quite narrow. In all cases, the dialogue with patients results in a thorough informed consent that includes the comprehensive discussion of the operative choices, risks, benefits, outcomes, long-term consequences, and expectations.

Table 5.1 Factors that influence operative choice

Health insurance restrictions	
Governmental regulations	
Patient's choice; surgeon's choice	
Patient characteristics:	Degree of adiposity
	Co-morbid conditions
	Previous surgery
	Underlying gastrointestinal disorders
	Eating habits and behavior
Miscellaneous factors	

5.4 Health insurance restrictions

Despite the existence of numerous publications that have demonstrated meaningful and sustainable weight loss after bariatric surgery, third party health insurance providers have established their own criteria for coverage, may not cover all of the operative procedures, or may impose additional criteria on coverage [27]. For example, the Food and Drug Administration (FDA) approved the use of the Lap-Band™, a laparoscopic adjustable gastric band, in June 2001. However for many subsequent years, several insurance carriers refused to provide coverage claiming it was "investigational" or "experimental." Currently, many of these companies have changed their policy and now cover the band in response to the thousands of publications, over 10 years of clinical experience, and the several hundred thousand patients who have had the band placed. However, some insurance carriers still fail to cover the band or only do so under certain circumstances where the gastric bypass would not be indicated such as patients with Crohn's Disease, abdominal radiation, or multiple previous abdominal surgeries.

There is a similar disparity in the coverage for the sleeve gastrectomy. Currently, few third party payers include this procedure as a covered benefit. They believe that the procedure is still too new to evaluate for appropriateness. However, there is a growing body of literature that demonstrates the benefits of this procedure, some with even 5-year follow up. Slowly more and more payers are adding sleeve gastrectomy to their coverage.

Unfortunately, for most patients, health insurance policy will take priority over all other factors in operative choice as the majority of patients rely on private health insurance to cover the cost of their surgery.

5.5 Governmental regulations

For many patients, government policy may also determine the operative procedure options. This is particularly true for patients who rely on either Medicaid or Medicare for health insurance coverage. In 2006, the Centers for Medicare and Medicaid Services declared that it would cover bariatric surgical procedures for appropriately selected patients [28]. At this time, coverage is only for the gastric band, Roux-en-Y gastric bypass, or the duodenal switch. The sleeve gastrectomy is not covered.

Many states have also established legislation regulating coverage for bariatric surgery [29]. In Massachusetts, patients with Medicaid would be covered for bariatric surgery, but only for the gastric bypass. Coverage for other bariatric procedures requires exceptional circumstances and additional documentation making them more difficult to obtain approval. Therefore, like insurance restrictions, governmental policy restrictions often take priority over all other considerations.

5.6 Patient's choice

In the current healthcare climate, patients have more control in decision-making than in the distant past. Patients are generally better informed and capable of deciding which bariatric operative procedure would be best for them. This is due, in part, to the tremendous wealth of information at the disposal of the patient on the internet. In addition, the direct to consumer marketing by the band manufacturers and from bariatric surgical programs affords prospective patients additional sources of information (albeit sometimes biased). By the time most patients meet their surgeon they already know which procedure they want. Some may have done an extensive search on the internet, while others may have had friends or family members who had a particular procedure and did well post-operatively and therefore ask for a certain operative procedure.

Moreover, there are patients who only want the surgical procedure with the least amount of risk. The adjustable gastric band, with a 30-day mortality of 0.1% and low risk of band erosion or slippage (1–4%) [7, 9] has the least risk as there are no staple lines or anastomoses, the band is adjustable, and if required can be removed. On the other hand, the gastric bypass and the biliopancreatic diversion have the highest risk as there are multiple staple lines and anastomoses. Mortality ranges from 0.3 to 1.6% [12,13]. The risk of major early complications, anastomotic leak, bleeding, or obstruction, occurs in 1–5% of cases [14]. Somewhere in the

middle of the "risk range" is the sleeve gastrectomy. There are only a few staple lines and no anastomoses. Lee *et al.* reported an anastomotic leak rate of 1.4% in their series of 216 patients who underwent a sleeve gastrectomy [30]. Major complications were 4.6% with no reported deaths [30].

It is generally considered standard of care for a bariatric program to offer patients seeking bariatric surgery educational materials and to obtain a thorough and comprehensive informed consent before proceeding with surgery. That informed consent should include information on several operative procedures including complications, expectations, outcomes, and potential long-term consequences [31].

Whether patients should have sole control of which procedure to undergo has not been determined. Patients may have unrealistic expectations of a specific procedure, or perhaps their bariatric clinicians may feel strongly that the procedure selected by the patient may not be the best option. On the other hand, patients may have circumstances or issues that would favor one procedure over another. An example might be the patient who is the sole income earner for a family and therefore is fearful of potential gastric bypass complications and as a result chooses the band.

Agreeing to proceed with the operation chosen by the patient but not felt by the clinicians to be best for the patient raises several ethical dilemmas. Firstly, there is currently no published evidence that has evaluated the outcomes of procedures chosen by patients versus procedures chosen by the clinical team. Secondly, patients may be less inclined to participate in their aftercare if they are obligated to undergo a procedure they truly did not want. Thirdly, in the event of a complication, a patient given an operation that they did not choose may be more apt to be angry and seek legal assistance. They might feel the complication they have suffered would not have occurred had they received the operation they wanted. Lastly, from a more general perspective, is it ever ethical to deny a patient their choice when there is no overwhelming evidence that one choice is truly better than another?

It is the practice of the authors to always provide the patient with the operative procedure that they choose as long as there are no contraindications to that choice. For example, we would not perform a gastric bypass on a patient with Crohn's disease even if it is their choice. For patients who request a procedure that we believe may not be best for them, we discuss our concerns with the patient and after a thorough discussion, provide the patient with the procedure that they then choose.

5.7 Surgeon's choice

Not surprisingly, surgeons will likely have strong opinions regarding which procedure to offer patients. In some cases, the surgeon only performs a single procedure and then would only offer that procedure to all potential surgical candidates. It is good policy that if a patient prefers a procedure that a particular surgeon does not perform or the surgeon believes that the patient (and the patient agrees) would be best served by an operative procedure which that surgeon does not perform, that the patient be referred to a colleague who is experienced with that procedure.

In many cases, patients may not have a strong opinion as to the best procedure for them and rely on the surgeon to make that determination for them. Surgeons are then likely to utilize their experience, understanding of the patient's behavioral make-up and health, and their interpretation of the medical literature. Unfortunately, the published literature offers conflicting recommendations. Even more concerning, these recommendations are often based on opinion not scientific study.

5.8 Patient characteristics

5.8.1 Degree of adiposity

The best procedure for the super-obese patient (BMI >50 kg m^{-2}) is still under debate. Many studies have reported that these patients are at higher risk for post-operative complications and mortality compared to patients with lower BMIs [32–35]. Several treatment options have been developed to address this. One approach is to perform a less complex procedure such as the gastric band or the vertical sleeve gastrectomy [25, 36, 37]. These procedures can generally be performed faster and do not have the complexity of two anastomoses to contend with, resulting in a reduction of peri-operative complications. On the other hand, some surgeons support the conclusions of Buchwald in his algorithm and would opt for a more radical procedure for weight loss believing that the simpler operations such as gastric banding would not generally result in sufficient weight loss [38, 39]. In contrast, others have found no difference in outcomes for super-obese patients having gastric banding [40, 41].

Another approach for the super-obese patient that has garnered favor in some programs is a two-staged approach. Here, the initial procedure is a less complex one such as the adjustable gastric band or sleeve gastrectomy. Patients will lose weight and improve their overall operative risk at which time a second more definitive operation converting the patient to a gastric bypass or biliopancreatic diversion (with or without duodenal switch). Regan *et al*. demonstrated that a two-staged approach reduced mortality for patients with BMIs ≥ 60 kg m^{-2} undergoing laparoscopic gastric bypass [23]. Pre-operative weight loss may afford the same benefits as a two-staged approach without the risk and cost of a second operation. Abeles *et al*. found that patients with BMIs ≥ 60 kg m^{-2} could undergo a single stage laparoscopic gastric bypass safely with pre-operative weight loss and strict attention to intra-operative details [42].

5.8.2 Co-morbid conditions

Taking a detailed history is of paramount importance. Knowledge of a patient's co-morbidities, such as type 2 diabetes mellitus, hypertension, hypercholesterolemia, and sleep apnea, may influence the surgeon's opinion regarding the most appropriate operation. In addition to BMI, the presence of co-morbid conditions can deem patients higher risk, which could influence the surgical options considered. As stated above, high-risk patients may be offered less complex procedures or even a staged approach.

It is currently well recognized that bariatric surgery can improve or even resolve many obesity-associated health conditions including type 2 diabetes, hypertension, sleep apnea, gastroesophageal reflux, and infertility [5, 43–47]. However, the success of improving or resolving these conditions varies by procedure [3] (Table 5.2).

In his meta-analysis, Buchwald *et al*. demonstrated that type 2 diabetes mellitus resolves in 84% of gastric bypass patients and 98% of biliopancreatic diversion patients, but in only 38% of patients after gastric banding. Similar findings were shown for hypertension. Sleep apnea improved similarly for all three of the above-mentioned procedures. Interestingly, the beneficial effects on some of these conditions are not weight loss dependent but rather due to some other physiologic change [48]. For example, most type 2 diabetics have resolution of their disease within days after gastric bypass or biliopancreatic diversion long before there is any weight loss, while band patients only see improvement after weight loss has commenced [12, 49]. Therefore, many surgeons might consider influencing patients who have severe diabetes to consider gastric bypass or biliopancreatic diversion instead of gastric banding.

Table 5.2 Resolution of co-morbid conditions

	GBP	Band	BPD± DS
Diabetes	84%	38%	98%
Hyperlipidemia	94%	71%	100%
Hypercholesterolemia	95%	78%	100%
Hypertriglyceridemia	94%	77%	100%
Hypertension	75%	43%	81%
Sleep apnea	87%	95%	95%

GBP, gastric bypass; BPD ± DS, biliopancreatic diversion, duodenal switch.
Source: Ref [26].

5.8.3 Previous surgery

Past surgical history of a patient can factor into the decision making process. It is important to obtain operative reports to ascertain exactly what was done previously. This information can change the surgeon's operative approach, especially if the patient has had prior gastric surgery. For example, a surgeon may decide to bring the roux limb of the gastric bypass antecolic, instead of retrocolic, in a patient who has had a prior colectomy in order to avoid disrupting the blood supply to the colon. A history of a small bowel resection may alter the site of an enteroenterostomy during a gastric bypass or biliopancreatic diversion. A previous fundoplication for gastroesophageal reflux may prompt the surgeon to offer a biliopancreatic diversion as opposed to the more risky choice of taking down the wrap and performing a gastric bypass. In addition, scar tissue and adhesions may be extremely thick and fibrotic resulting in an extensive lysis of adhesions or even in the surgeon being unable to perform any bariatric procedure safely.

5.8.4 Underlying gastrointestinal disorders

Patients with Crohn's disease are prone to developing intestinal fistulas. As a result, a surgeon may shy away from a gastric bypass or biliopancreatic diversion (in favor of an adjustable gastric band) where, in this patient population, anastomoses may not heal properly resulting in a leak or enterocutaneous fistula. Similarly, patients with a history of external beam radiation to the abdomen or pelvis may have extremely friable bowels resulting in an anastomotic leak or enterocutaneous

fistula. As a result, a surgeon may consider an adjustable band or a sleeve gastrectomy in these patients [50].

5.8.5 Eating habits and behavior

The eating habits of patients may sway some surgeons to one procedure over another. These habits include binging and eating sweets. There is some controversy as to the best surgical procedure for patients who are "sweet eaters." Sugarman reported better weight loss results after gastric bypass for patients who eat sweets [51, 52]. However, Hudson reported similar weight loss after adjustable gastric banding for both sweet eaters and non-sweet eaters [53]. In our practice, we recommend the gastric bypass to patients who eat sweets to take advantage of the dumping syndrome that occurs as sugars pass directly into the jejunum. This often leads patients to avoid concentrated sweets altogether. Patients with a history of eating high calorie liquids, such as ice cream, must change their eating habits as this is one way to fail any bariatric procedure.

5.9 Case example

Case 1: A 30-year-old woman with a BMI of 40 kg m^{-2} and no obesity related co-morbidities seeks to discuss surgical options in light of her recent marriage, and anticipates pregnancy in the future. This patient may benefit from a purely restrictive procedure, such as a gastric band or sleeve gastrectomy as opposed to a malabsorptive procedure (gastric bypass or biliopancreatic diversion) in order to avoid any vitamin deficiencies associated with the latter. In addition, the gastric band is an appealing choice in this patient as it may be completely deflated during pregnancy to ensure adequate nutrition and weight gain and reinflated post-partum to assist with weight loss.

Case 2: A 48-year-old man with a BMI of 39 kg m^{-2} reports a history of gastroesophageal reflux disease and type 2 diabetes. He also confesses to midnight cravings of cake and ice cream. For this patient, the gastric bypass may be the best option for several reasons. The resolution of diabetes soon after gastric bypass is well known, even before any significant weight is lost [43, 44]. In addition, the best operation for a MO patient with reflux is the gastric bypass [54–56]. So, why not an adjustable band? This patient is a "sweet eater." Although there may be some controversy as to the optimal surgical procedure in these patients, in our practice, we recommend the gastric bypass to take advantage of the dumping syndrome, which often leads patients to avoid concentrated sweets altogether.

5.10 Conclusion

There is no consensus or criteria for choosing one surgical weight loss procedure over another. The best choice for one patient may not be the most appropriate for another. Generally speaking, the more radical (or risky) the procedure is, the better the weight loss results. Carrying this forward, heavier patients are more successful with more radical procedures. Some patients will have personality characteristics that may make them better candidates for one procedure over another. Matching the right patient with the right operation requires balancing the operative risks with outcomes while also considering the individual patient's lifestyle, personality and most importantly, their wishes.

References

1. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults – The Evidence Report. National Institutes of Health. *Obes Res* 1998; **6** Suppl 2: 51S–209S.
2. Allison DB, Fontaine KR, Manson JE, Stevens J, VanItallie TB. Annual deaths attributable to obesity in the United States. *JAMA* 1999; **282**: 1530–8.
3. Buchwald H, Avidor Y, Braunwald E. Bariatric surgery: a systematic review and meta-analysis. *JAMA* 2004; **292**: 1724–37.
4. Adams TD, Gress RE, Smith SC, *et al*. Long-term mortality after gastric bypass surgery. *N Engl J Med* 2007; **357**: 753–61.
5. Sjostrom L, Lindroos AK, Peltonen M, *et al*. Lifestyle, diabetes, and cardiovascular risk factors 10 years after bariatric surgery. *N Engl J Med* 2004 ; **351**: 2683–93.
6. Belachew M, Legrand MJ, Defechereux TH, Burtheret MP, Jacquet N. Laparoscopic adjustable silicone gastric banding in the treatment of morbid obesity. A preliminary report. *Surg Endosc* 1994; **8**: 1354–6.
7. Vella M, Galloway DJ. Laparoscopic adjustable gastric banding for severe obesity. *Obes Surg* 2003; **13**: 642–8.
8. O'Brien PE, Dixon JB. Lap-band: outcomes and results. *J Laparoendosc Adv Surg Tech A* 2003; **13**: 265–70.
9. Buchwald H, Consensus Conference Panel. Consensus conference statement bariatric surgery for morbid obesity: health implications for patients, health professionals, and third-party payers. *Surg Obes Relat Dis* 2005; **1**: 371–81.
10. MacLean LD, Rhode BM, Sampalis J, Forse RA. Results of the surgical treatment of obesity. *Am J Surg* 1993; **165**: 155–60; discussion 160–2.
11. MacLean LD, Rhode BM, Nohr CW. Late outcome of isolated gastric bypass. *Ann Surg* 2000; **231**: 524–8.
12. Pories WJ, Swanson MS, MacDonald KG, *et al*. Who would have thought it? An operation proves to be the

most effective therapy for adult-onset diabetes mellitus. *Ann Surg* 1995; **222**: 339–50; discussion 350–2.

13. Benotti PN, Forse RA. The role of gastric surgery in the multidisciplinary management of severe obesity. *Am J Surg* 1995; **169**: 361–7.
14. Shikora SA, Kim JJ, Tarnoff ME, Raskin E, Shore R. Laparoscopic Roux-en-Y gastric bypass: results and learning curve of a high-volume academic program. *Arch Surg* 2005; **140**: 362–7.
15. Halverson JD. Micronutrient deficiencies after gastric bypass for morbid obesity. *Am Surg* 1986; **52**: 594–8.
16. Amaral JF, Thompson WR, Caldwell MD, Martin HF, Randall HT. Prospective hematologic evaluation of gastric exclusion surgery for morbid obesity. *Ann Surg* 1985; **201**: 186–93.
17. Rhode BM, Arseneau P, Cooper BA, Katz M, Gilfix BM, MacLean LD. Vitamin B-12 deficiency after gastric surgery for obesity. *Am J Clin Nutr* 1996; **63**: 103–09.
18. Brolin RE, Leung M. Survey of vitamin and mineral supplementation after gastric bypass and biliopancreatic diversion for morbid obesity. *Obes Surg* 1999; **9**: 150–4.
19. Scopinaro N, Gianetta E, Adami GF, *et al*. Biliopancreatic diversion for obesity at eighteen years. *Surgery* 1996; **119**: 261–8.
20. Marceau P, Hould FS, Simard S, *et al*. Biliopancreatic diversion with duodenal switch. *World J Surg* 1998; **22**: 947–54.
21. Langer FB, Bohdjalian A, Felberbauer FX, *et al*. Does gastric dilatation limit the success of sleeve gastrectomy as a sole operation for morbid obesity? *Obes Surg* 2006; **16**: 166–71.
22. Almogy G, Crookes PF, Anthone GJ. Longitudinal gastrectomy as a treatment for the high-risk super-obese patient. *Obes Surg* 2004; **14**: 492–7.
23. Regan JP, Inabnet WB, Gagner M, Pomp A. Early experience with two-stage laparoscopic Roux-en-Y gastric bypass as an alternative in the super-super obese patient. *Obes Surg* 2003;**13**: 861–4.
24. Fuks D, Verhaeghe P, Brehant O, *et al*. Results of laparoscopic sleeve gastrectomy: a prospective study in 135 patients with morbid obesity. *Surgery* 2009; **145**: 106–13.
25. Tagaya N, Kasama K, Kikkawa R, *et al*. Experience with laparoscopic sleeve gastrectomy for morbid versus super morbid obesity. *Obes Surg* 2009; **19**: 1371–6.
26. Buchwald H. A bariatric surgery algorithm. *Obes Surg* 2002; **12**: 733–46; discussion 747–50.
27. Safadi BY. Trends in insurance coverage for bariatric surgery and the impact of evidence-based reviews. *Surg Clin North Am* 2005; **85**: 665–80.
28. Elmore BL, Phillips WT. Bariatric surgery coverage decision: opportunities and limitations. *Healthc Financ Manage* 2006; **60**: 52–4.
29. Vanek VW. State laws on insurance coverage for bariatric surgery: help or a hindrance? *Surg Obes Relat Dis* 2005; **1**: 424–9.
30. Lee CM, Cirangle PT, Jossart GH. Vertical gastrectomy for morbid obesity in 216 patients: report of two-year results. *Surg Endosc* 2007; **21**: 1810–16.
31. Sabin J, Fanelli R, Flaherty H, *et al*. Best practice guidelines on informed consent for weight loss surgery patients. *Obes Res* 2005; **13**: 250–3.
32. Ren CJ, Patterson E, Gagner M. Early results of laparoscopic biliopancreatic diversion with duodenal switch: a case series of 40 consecutive patients. *Obes Surg* 2000; **10**: 514–23; discussion 524.
33. Oliak D, Ballantyne GH, Davies RJ, Wasielewski A, Schmidt HJ. Short-term results of laparoscopic gastric bypass in patients with BMI > or = 60. *Obes Surg* 2002; **12**: 643–7.
34. Dresel A, Kuhn JA, McCarty TM. Laparoscopic Roux-en-Y gastric bypass in morbidly obese and super morbidly obese patients. *Am J Surg* 2004; **187**: 230–2; discussion 232.
35. Fazylov RM, Savel RH, Horovitz JH, *et al*. Association of super-super-obesity and male gender with elevated mortality in patients undergoing the duodenal switch procedure. *Obes Surg* 2005; **15**: 618–23.
36. Myers JA, Sarker S, Shayani V. Treatment of massive super-obesity with laparoscopic adjustable gastric banding. *Surg Obes Relat Dis* 2006; **2**: 37–40; discussion 40.
37. Jan JC, Hong D, Pereira N, Patterson EJ. Laparoscopic adjustable gastric banding versus laparoscopic gastric bypass for morbid obesity: a single-institution comparison study of early results. *J Gastrointest Surg* 2005; **9**: 30–9; discussion 40–1.
38. Bueter M, Thalheimer A, Lager C, Schowalter M, Illert B, Fein M. Who benefits from gastric banding? *Obes Surg* 2007; **17**: 1608–13.
39. Chevallier JM, Paita M, Rodde-Dunet MH, *et al*. Predictive factors of outcome after gastric banding: a nationwide survey on the role of center activity and patients' behavior. *Ann Surg* 2007; **246**: 1034–39.
40. Fielding GA. Laparoscopic adjustable gastric banding for massive superobesity (> 60 body mass index kg/m^2). *Surg Endosc* 2003; **17**: 1541–5.
41. Singhal R, Guy A, Kitchen M, Hunt K, Nidrika S, Super P. High BMI should not preclude laparoscopic banding: result of 1000 patients from a bariatric center in UK. *Obes Surg* 2007; **17**: 1037.
42. Abeles D, Kim JJ, Tarnoff ME, Shah S, Shikora SA. Primary laparoscopic gastric bypass can be performed safely in patients with BMI ≥ 60. *J Am Coll Surg* 2009; **208**: 236–40.
43. Smith BR, Hinojosa MW, Reavis KM, Nguyen NT. Remission of diabetes after laparoscopic gastric bypass. *Am Surg* 2008; **74**: 948–52.

44. Sugerman HJ, Wolfe LG, Sica DA, Clore JN. Diabetes and hypertension in severe obesity and effects of gastric bypass-induced weight loss. *Ann Surg* 2003; **237**: 751–6; discussion 757–8.
45. Dixon JB, O'Brien PE. Changes in comorbidities and improvements in quality of life after LAP-BAND placement. *Am J Surg* 2002; **184**(6B): 51S–4S.
46. Hinojosa MW, Varela JE, Smith BR, Che F, Nguyen NT. Resolution of systemic hypertension after laparoscopic gastric bypass. *J Gastrointest Surg* 2009; **13**: 793–7.
47. Fritscher LG, Canani S, Mottin CC, *et al*. Bariatric surgery in the treatment of obstructive sleep apnea in morbidly obese patients. *Respiration* 2007; **74**: 647–52.
48. Rubino F, Forgione A, Cummings DE, *et al*. The mechanism of diabetes control after gastrointestinal bypass surgery reveals a role of the proximal small intestine in the pathophysiology of type 2 diabetes. *Ann Surg* 2006; **244**: 741–9.
49. Wickremesekera K, Miller G, Naotunne TD, Knowles G, Stubbs RS. Loss of insulin resistance after Roux-en-Y gastric bypass surgery: a time course study. *Obes Surg* 2005; **15**: 474–481.
50. Frezza EE. Laparoscopic vertical sleeve gastrectomy for morbid obesity. The future procedure of choice? *Surg Today* 2007; **37**: 275–81.
51. Sugerman HJ, Londrey GL, Kellum JM, *et al*. Weight loss with vertical banded gastroplasty and Roux-Y gastric bypass for morbid obesity with selective versus random assignment. *Am J Surg.* 1989; **157**: 93–102.
52. Sugerman HJ, Starkey JV, Birkenhauer R. A randomized prospective trial of gastric bypass versus vertical banded gastroplasty for morbid obesity and their effects on sweets versus non-sweets eaters. *Ann Surg* 1987; **205**: 613–24.
53. Hudson SM, Dixon JB, O'Brien PE. Sweet eating is not a predictor of outcome after Lap-Band placement. Can we finally bury the myth? *Obes Surg* 2002; **12**: 789–94.
54. Ikramuddin S. Surgical management of gastroesophageal reflux disease in obesity. *Dig Dis Sc.* 2008; **53**: 2318–2329.
55. Tai CM, Lee YC, Wu MS, *et al*. The effect of Roux-en-Y gastric bypass on gastroesophageal reflux disease in morbidly obese Chinese patients. *Obes Surg* 2009; 19: 565–70.
56. Varela JE, Hinojosa MW, Nguyen NT. Laparoscopic fundoplication compared with laparoscopic gastric bypass in morbidly obese patients with gastroesophageal reflux disease. *Surg Obes Relat Dis* 2009; **5**: 139–43.

Chapter 6

Informed consent

Steve E. Raper

6.1 Introduction

Informed consent is a complex ethical, and legal doctrine developed to ensure respect for patient self-determination (autonomy) in making healthcare decisions, and to promote the patients' well-being (beneficence). Prior to World War II patients were told of the physician's plans for treatment and were expected to give consent without question. Patient autonomy then surpassed physician beneficence, that is, a patient's consent was necessary; but first adequate information had to be imparted to allow that patient's consent to be knowing and voluntary. A series of seminal legal cases in the ensuing decades further refined the doctrine. Laws were passed to codify patient rights and physician duties. Federal regulations, promulgated through the Centers for Medicare and Medicaid Services, outlined physician and healthcare facility consent requirements. Medical associations, like the American College of Surgeons, and accreditation bodies, like The Joint Commission developed statements regarding required elements to be disclosed to patients.

The informed consent process for bariatric surgery deals with a narrow set of considerations. Bariatric procedures are elective, the number of available operations is relatively small, and a great deal is known about the risks and benefits. With rare exceptions, prospective patients are competent to consent – minors are a special case. This chapter will review the doctrine of informed consent focusing especially on the tensions that have arisen between the competing principles of patient autonomy and physician beneficence. Next, the legal dimension, in both case law and statutory approaches will be discussed. Individual elements of a typical consent disclosure – as recommended by a variety of sources – will be compared and contrasted. Lastly, a survey of recent attempts to improve the process of informed consent will be undertaken. It is hoped that at the end of the chapter the reader will have a clearer idea of why the informed consent process is so important. The physician should be able to do a better job of obtaining consent when faced with a patient deciding whether or not to undergo a bariatric procedure.

6.2 History

The Hippocratic Oath says nothing about informed consent. Hippocrates wrote that it was better to cure the patient than to tell him what was going to happen. When cure was not possible, however, the best physician gave the most correct prognosis. Conversations between physicians and patients have always been used by physicians to instill confidence and to persuade patients to undertake a prescribed course of treatment. Patients were not really free to consent; complying with a physician's orders was expected. In nineteenth century America, several authors identified the requirement of disclosure and consent in surgical cases, and beneficence on the part of surgeons was not often employed to override a patient's refusal to undergo an operation, even if it was life-saving. By the early twentieth century, as patients came to expect higher quality care, lawsuits proliferated. Where surgery was concerned, battery was the usual cause of action if no consent was obtained. A 1934 article, 'Malpractice suits: Their cause and prevention', cautioned surgeons to "Secure consent before you operate" [1].

Prior to World War II, the dominant principle of consent could be articulated as physician beneficence. Surgeons decided what operation was to be performed amongst any alternatives and balanced the risks and benefits to be borne by the patient. Surgeons were expected to get consent from patients for the operations to be performed and the patients' options were to "take it or leave it."

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

6.3 Ethical considerations

In response to the barbarism of Nazi physicians, the Nuremberg tribunal promulgated the Nuremberg Code: ten basic principles for the conduct of human subject research. The Nuremberg judges went to great lengths to define voluntary consent, including the subject's capacity to give consent, and the information that investigators must provide to subjects. Although initially directed to medical research, the Nuremberg Code has proven influential in the medical and surgical treatment of patients as well.

Further refinements of the Nuremberg Code were developed in the United States, under direction of the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research (The Belmont Commission). The Belmont Report is a deceptively short but seminal document consisting of three guiding principles – respect for persons, beneficence, and justice – by which human subject research should be performed [2]. Although the Belmont Report specifically addresses human subject research, the three principles promulgated are just as applicable in the setting of clinical care. In particular, the acknowledgement that patients should be able to make their own medical decisions, even if not in agreement with those chosen for them by their physicians. The third principle – justice – is less concerned with the doctrine of consent. Distributive justice is meant to ensure that those who receive the benefits of medical treatment should also bear its burdens. Injustice occurs when some benefit to which a person is entitled is denied without good reason or when some burden is imposed unduly. In the context of informed consent, justice is a lesser principle, as all who propose surgery must obtain consent.

Ethically speaking, patients have a right to informed consent. The right to informed consent becomes progressively more important as proposed diagnostic or therapeutic options entail greater risks. For routine phlebotomy, or the prescribing of most medicines, informed consent is generally not required, while for surgical procedures consent becomes mandatory. The patient's right to give informed consent imposes two obligations on physicians: to secure consent and to provide enough information so consent is informed. Adequate informed consent depends on both patient and physician factors.

In 1982, the President's Commission for the Study of Ethical Problems in Medicine and Biomedical and Behavioral Research (the President's Commission) released a landmark report entitled *Making Health Care Decisions: The Ethical and Legal Implications of Informed Consent in the Patient–Practitioner Relationship*. Earlier pronouncements, such as the Nuremberg Code and Belmont Report, dealt mainly with human subject protection in research. The President's Commission directly addressed informed consent in the context of medical care. The Commission identified as central to the patient–physician consent encounter two principles identical to those advocated by the Belmont Commission in the research setting: respect for patient autonomy, and beneficence.

6.4 Patient autonomy

Autonomy is "an individual's exercise of the capacity to form, revise, and pursue personal plans for life." Respect for autonomy is based on the belief that each person knows what is best for themselves. Decisions about one's healthcare are among the most important an individual should make, hence autonomy should be strongly respected in the informed consent process. Under most circumstances, well-being is closely tied to an individual's subjective judgment about what is best for him/herself. Three elements are defined for when an individual acts autonomously with regard to informed consent: 1) consent must be intentional; 2) consent must be with understanding; and 3) consent must be without controlling influences.

6.4.1 Intentionality

To be intentional, an individual must plan for and will an action. In the case of informed consent, the action is a decision for an operation. It is a matter of intuition that acts done knowingly and with intent will be imputed to that individual. Even if a physician carries out a treatment in harmony with an individual's values but doesn't allow an individual to plan for and make the choice, no respect has been paid to the individual's autonomy. The individual may come to believe that he/she did not participate in, or approve of the choice. Uncertainty about whether a physician's choice of treatment is what the patient would have chosen for themselves, also leads to the possibility of frustration on the part of the patient when his/her wishes are ignored or directly contradicted. Both repudiation of the choice and frustration with a contrary decision can lead to sub-optimal outcome and the enhanced potential for litigation.

There are also circumstances under which an individual's informed consent is not required. Meisel has identified four exceptions in which treatment may be

rendered without informed consent: the emergency exception, incompetency, waiver, and therapeutic privilege [3]. With respect to bariatric procedures, the emergency exception is rarely invoked. Emergencies are generally understood to exist when patients are unconscious or in such pain that they cannot be attentive to imparted information, and further that the consequence of withholding treatment until patients are able to give consent is death or significant disability. Incompetency is likewise not a common circumstance. To derive significant benefit from bariatric surgery, an individual should be able to comply with diet and exercise recommendations; hence competency is usually a necessary condition to proceeding with bariatric surgery. Consent for minors requires, at a minimum assent of the patient and informed consent of the parents [4].

The patient's right to autonomy in general and informed consent in particular is, however, an alienable right, one that under some circumstances can be intentionally waived. Waiver, as in other legal circumstances should be voluntary, intelligent, and knowing. Other patients will try to waive their right to consent, wanting minimal, or no information, asking the physician to "do what you think is best, Doc …" or attempt to transfer the right to others, claiming incapacity to make their own decisions, preferring instead to allow a family member, other surrogate or even the physician her/himself to decide. Some patients require from their surgeon a great deal of disclosure. Frequently, especially in prospective bariatric surgical patients, they have acquired information of their own from the internet and other sources. They come to the physician–patient encounter with a long list of detailed questions. Such patients fully exert their right to consent, and from a moral standpoint are easiest to consent. The last exception is therapeutic privilege. The privilege is invoked by physicians when the information imparted by physician to patient is likely to harm the patient more than help them. Again, such an exception is usually invoked in the case of terminal cancer, and even then ethical problems arise.

6.4.2 Understanding

"Understanding" is defined as when a person has an adequate grasp of all information that contributes to appreciation of the circumstances that: correctly describe [1] the nature of the action, and the foreseeable consequences and possible outcomes that might follow as a result of performing or not performing the action [2]. To the extent that this ideal is less than satisfied, an action is based on less than full understanding, and thus is not a fully autonomous action. This formulation is useful for purposes of a consent discussion, and bears heavily on the risk/benefit analysis to be discussed during the consideration of beneficence. Understanding also requires competence of an individual, which in most circumstances is within the capacity of the individual who must decide a course of action. In cases of children, however, capacity to decide is nontrivial, and will require the input of the parents or other legal guardian.

A well-meaning physician can provide consent forms at the correct reading level, clear graphic representations of what is to be done, and do their utmost to answer any and all questions, and yet the patient can waive the right to know what is proposed by choosing not to comprehend. Providing adequate information is no guarantee that a patient understands what is to be done. This lack of understanding may be purposeful, as when a patient "tunes out" the physician, specifically choosing not to understand. Alternatively, the information regarding the proposed procedure may not be provided in a way the patient can understand, and the patient chooses not to ask for clarity. Even where understanding is at least partial, most physicians have observed patients affirmatively nodding to noncomprehended information. A good defense against this lack of comprehension is to reiterate important information at more than one time in more than one format.

6.4.3 Lack of controlling influences

True patient autonomy allows choices to be made in the absence of external control. In practice, it is rarely possible for patients to give informed consent in the absence of external pressures. The patient's decision-making process is often affected – with or without awareness – by persuasion, manipulation or (infrequently) coercion. These terms comprise a spectrum of disclosure which influences patient autonomy in the decision-making process. At one end of the spectrum, persuasion is commonly practiced. Potential bariatric patients, even prior to the physician encounter, are exposed to advertisements on television, billboards, word-of-mouth, and the internet. Images of slender individuals with well-defined physiques are held out as most desirable by others. As physicians and hospitals compete for patients, each makes a claim as to why the patient should select a particular program. Often, by

the time the patients arrive in the surgeon's office, they have already made a choice as to what procedure they would like to have performed.

6.5 Physician beneficence

Physician beneficence versus respect for the patient as a person has arisen into a contemporary moral tension between two important ethical principles. A physician may simply agree with a patient's decision, regardless of the consequences. Such a position would be fully consonant with a principle of patient autonomy. However, a physician should not allow a patient to make a choice that, in the physician's judgment, is ill-advised without first exploring the patient's rationale. Full disclosure of information is required so that a patient may make informed consent. The President's Commission's solution is not satisfying:

> "The Commission recognizes that its vision of healthcare decision-making may involve greater commitments of time on the part of health professionals. Because of the importance of shared decision-making based on mutual trust, not only for the promotion of patient well-being and self-determination but also for the therapeutic gains that can be realized, the Commission recommends that all medical and surgical interventions be thought of as including appropriate discussion with patients. Reimbursement to the professional should therefore take account of time spent in discussion rather than regarding it as a separate item for which additional payment is made."

By routinely linking procedures which require consent to actual performance of such procedures leads to incentives to perform procedures rather than encourage a course of watchful waiting or less invasive therapy.

Beneficence means to strive for, as a goal "first do no harm." This goal, also defined as the enhancement of patient well-being, is best put into practice by minimizing risks, and maximizing potential benefits. Although the focus over the past half-century has been to protect patient autonomy, surgeons cannot morally abrogate their duty to maintain the patient's well-being. Beneficence and autonomy are not different terms for the same value, and well-being is not a concrete concept that has a single definition solely within the competency of healthcare providers to define. Although shared decision-making requires that the practitioner seeks to understand each patient's needs and allows them to make a reasonable choice to meet those needs, the physician is charged with providing the most appropriate set of options to give an individual patient.

The physician cannot be passive in the encounter. In discussing a proposed treatment with the patient, the physician may – with or without awareness – variably affect the decision-making process by employing persuasion, manipulation, or (infrequently) coercion. Persuasion, although an external influence, is generally non-controlling, and still allows volitional choice through appeal to reason.

Manipulation is the influence of an individual by altering the available choices, or altering the information imparted, in order to make one of a number of choices seem most reasonable. In discussions of informed consent, manipulation is a major concern. Regardless of the sophistication of the patient, or how much information the patient finds prior to the consent discussion, a significant imbalance in the relative knowledge base between physician and patient must exist. The choice by the physician of what and how to disclose information on the various aspects of a given surgical procedure can either be "spun" in a neutral direction or so as to introduce a significant bias in the patient's decision-making process.

Coercion is morally unacceptable in the consent setting, and is generally regarded as one individual presenting a credible threat of unwanted and avoidable harm that the person making a choice is unable to resist. For example, a surgeon who states "You'll die if you don't have this operation" is trying to coerce the patient in an ethically unacceptable way, and negates that patient's fully informed consent.

The physician encounter, then, is designed to reinforce those attitudes which caused the patient to seek out the physician in the first place. A terse disclosure of risks and benefits provides little opportunity for the patient to understand the context in which a given procedure will be performed, and may impact the ability to ask relevant questions which are generally a sign of comprehension. At the opposite end of the spectrum, expansive discussion of risks, potential benefits, and treatment alternatives entails the concern that patients may "tune out" as a result of information overload. Provision of pathophysiologic minutiae and excessive technical detail could confound rather than enlighten. The patient may well be left with the impression that the planned operation is too complex to understand. The physician by default becomes the decision-maker.

The promotion of well-being is an important value even in decisions about patients who can make their own choices. The boundaries of the interventions that

health professionals present for consideration are set by the concept of well-being. Informed consent does not mean the patient can insist upon any and all procedures that they might wish. It is a choice among medically accepted and available options, all of which are believed to have some possibility of promoting the patient's welfare, including the option of non-surgical interventions with regard to bariatric surgery.

All treatment options must be presented, including procedures that the surgeon does not perform to ensure an educated decision. It is necessary to understand that a thorough discussion of the alternatives for treatment, the risks attendant upon each alternative, and the potential benefits of each therapeutic option must be addressed in detail with the patient. Patients who are aware of the possible complications of a given procedure will be more likely to identify the development of such complications earlier in the course of their convalescence than patients who have no knowledge of the potential harm incurred by undergoing a bariatric procedure.

The traditional approach to balancing the two, sometimes competing, principles of autonomy and beneficence have led to a widespread consensus that shared decision-making is the norm with regard to informed consent. According to the President's Commission, many physicians and patients said they believed increased emphasis on the conversation, which takes place in the context of informed consent, would give the patient a better understanding of the medical condition and treatment, would improve physician performance in terms of the honesty and scope of the informed consent discussion, and would generally improve the doctor–patient relationship. Physicians, in particular, also claimed that greater patient involvement would improve the quality of care, because it would improve compliance and would make patients more cooperative and more willing to accept the doctor's judgment, especially if the doctor's judgment was for a different procedure than that which was first chosen by the patient.

Bariatric surgical procedures are a good example of how healthcare professionals often reflect their own value preferences when the surgeon favors one alternative over another. Many are matters of personal choice and professional comfort dictated neither by sound medical data nor by a single agreed upon professional standard. Some physicians prefer laparoscopic gastric bypass; others prefer open procedures. The choice of vendor for an adjustable laparoscopically placed gastric band would be another example. However, determining what constitutes health, and, how it is best promoted, also requires knowledge of the patient's subjective preferences in pursuit of other goals and interests besides health. The preferences and interests of the individual patient's need to be given careful consideration by the healthcare practitioner, but it is the practitioner that must ultimately implement the patient's choice.

6.6 Legal considerations in informed consent

Autonomy of the individual in making decisions on healthcare treatment has been a priority of the legal system. Common law throughout the United States has centered on two major elements: the requirement to obtain consent, and the provision of adequate information to allow consent to be informed. Obtaining informed consent can be viewed as both an event and a process [5]. Informed consent is documentation that permission is obtained usually by a patient signature on a consent form. However, informed consent is also a process by which, through a variety of means, information is imparted to patients which allows them to give an informed consent; both are necessary from a legal standpoint.

6.6.1 The state courts

In state court tort claims, the focus of common law has been on the provision of information on risks. Much less emphasis has been placed on what must be told regarding expected outcomes, benefits, or alternatives, including no therapy. In general, modern lawsuits allege negligence in the consent process; it is unusual for physicians to perform procedures with no consent whatsoever. Operations performed without consent amount to unconsented touching, or battery. Battery is different from a negligent tort claim as in a standard malpractice claim. Battery may not be covered under traditional malpractice coverage, and physicians may be subjected to criminal rather than civil proceedings. At the least, damages may include a punitive component which markedly raises the amount of any settlement.

More common is the claim that a physician did not adequately disclose information about a procedure, and as a result, the patient was not able to give informed consent. Although battery claims may still be filed, the courts were uncomfortable finding for plaintiffs when consent was obtained but some complication which the

physician had not disclosed to the patient arose during or after the procedure. Battery claims generally did not allow the defense to provide experts to discuss community standards, juries could award punitive damages, and malpractice insurance did not cover such claims.

Initially, the decision of what information to disclose to individual patients was left to the discretion of the physician as long as the information was similar to that provided by other physicians – the so-called *professional standard*. In the 1960s the courts shifted the focus, from what a physician wanted to tell a patient, to what a reasonable patient would want to know.

The question is "What would a reasonable patient want to know?" An important ruling defined this as [1]:

> "… [W]hen a given procedure inherently involves a known risk of death or serious bodily harm, a medical doctor has a duty to disclose to his patient the potential of death or harm, and to explain in lay terms the complications that might possibly occur."

6.6.2 Legislative approaches to informed consent

Most state legislatures also have enacted statutes regarding the requirement for informed consent. Georgia's statute addresses many of the issues which arise in any consideration of consent and is used as an example. Most of the provisions are found in informed consent statutes throughout the nation, with some state-to-state variation. Georgia Code Title 31, Health, Chapter 9, Consent for Surgical or Medical Treatment §31–9–6.1 mandates that any person who undergoes (among others) any surgical procedure under general, spinal, or major regional anesthesia, must consent to such procedure and shall be informed in general terms of a number of elements.

These elements are:

(1) A diagnosis of the patient's condition requiring such proposed surgical or diagnostic procedure;
(2) The nature and purpose of such proposed surgical or diagnostic procedure;
(3) The material risks generally recognized and accepted by reasonably prudent physicians of infection, allergic reaction, severe loss of blood, loss or loss of function of any limb or organ, paralysis or partial paralysis, paraplegia or quadriplegia, disfiguring scar, brain damage, cardiac arrest, or death involved in such proposed surgical or diagnostic procedure which, if disclosed to a reasonably prudent person in the patient's position, could reasonably be expected to cause such prudent person to decline such proposed surgical or diagnostic procedure on the basis of the material risk of injury that could result from such proposed surgical or diagnostic procedure;
(4) The likelihood of success of such proposed surgical or diagnostic procedure;
(5) The practical alternatives to such proposed surgical or diagnostic procedure which are generally recognized and accepted by reasonably prudent physicians; and
(6) The prognosis of the patient's condition if such proposed surgical or diagnostic procedure is rejected.

The consent must be in writing, or it may not be presumed valid. If a written consent is signed by the patient or other authorized individual, then such consent is presumed to be valid.

The responsible physician, that is the physician who performs the procedure, must ensure that legally required information is obtained. The information may be disclosed through the use of video tapes, audio tapes, pamphlets, booklets, or other means of communication, or through conversations with nurses, physician's assistants, trained counselors, patient educators, or other similar persons known by the responsible physician to be knowledgeable and capable of communicating such information. Interestingly, the Georgia statute makes explicit that if any employee of a hospital or ambulatory surgical treatment center participates in consent conversations at the request of the responsible physician, the employee is considered to be solely the agent of the responsible physician.

A failure to comply with the requirements of the Georgia statute does not constitute a separate cause of action but may be added to a medical malpractice claims if: the patient suffered an injury which was proximately caused by the surgical or diagnostic procedure; information concerning the injury suffered was not disclosed as required; and that a reasonably prudent patient would have refused the surgical or diagnostic procedure or would have chosen a practical alternative to such proposed surgical or diagnostic procedure if such information had been disclosed.

There are circumstances under Georgia law in which consent is not required: emergencies, surgical or diagnostic procedures generally recognized by reasonably prudent physicians not to involve material risks to

the patient, or if the patient waives their right to consent by making a request in writing that the required information not be disclosed. Consent in Georgia is generally valid for 30 days. Consent obtained for surgical or diagnostic procedures is considered valid for not only the responsible physician, but also any medical personnel under the direct supervision and control of the responsible physician in the performance of such surgical or diagnostic procedure, and for all other medical personnel otherwise involved in the course of treatment of the patient's condition.

Surgeons should be aware of the laws in their particular state. An example is Arkansas, which has a specific statute with respect to performance of gastric bypasses, § 17–95–108, *Informed consent required for gastric bypass surgery*. By law, no gastric bypass surgery may be performed in Arkansas unless the physician performing the surgery has informed the patient in writing, as evidenced by the patient's signature, of the known risks and complications of the procedure, including, but not limited to: the surgery itself; all known and documented future complications that may occur as a result of the procedure; side effects that may result from vitamin deficiency and malnutrition; and the requirements for appropriate follow up. The Arkansas legislature left promulgation of the rules and regulations up to the State Medical Board, but required the State Board to utilize scientifically accepted information from national medical specialty boards, organizations, or governmental agencies in determining the specific content and lists of complications or side effects, or both, that must be included in the informed consent.

Another area of concern likely to become a more active issue in the future is that of a surgeon's competence with respect to individual procedures. For example, the Pennsylvania legislature passed a law, The Medical Care Availability and Reduction of Error (M-CARE) Act with a provision that explicitly noted that: "A physician may be held liable for failure to seek a patient's informed consent if the physician knowingly misrepresents to his patient his or her professional credentials, training, or experience."

The Pennsylvania law stops short of requiring physicians to disclose individual outcome data, presumably a patient must first ask for a physician's experience. However, the Pennsylvania statute is part of a growing trend to provide information that is not merely procedure specific.

Providing validated, risk-adjusted individual performance measures requires sophisticated database entry and data analysis. Currently, the accuracy of surgeon- and patient-specific performance rates for surgical procedures is illusory, complicating any legal obligation to communicate them as part of the informed consent process. Nonetheless, the discipline of surgery is in the process of developing information systems that allow for performance to be evaluated to a high degree of accuracy. In the meantime, if asked, patients should be informed of the unembellished number of procedures the surgeon has performed, providing a general idea of the surgeon's experience [6]. There is data to suggest that surgeon volume with respect to individual procedures has some effect on mortality [7].

6.7 The approaches of accrediting and credentialing administrative bodies to codification of informed consent

Regulatory and other accrediting bodies impose guidelines regarding all aspects of healthcare, including informed consent. The Centers for Medicare and Medicaid Services has also developed guidelines for consent (Table 6.1A). Such guidelines, however, are useful in providing bariatric surgeons with a guide to elements that constitute adequate informed consent. It should be noted that such recommendations do not supplant statutory requirements of the individual states, but frequently similar elements are to be found in both places. The Joint Commission has standard RI.2.40 relating to elements required of healthcare organizations, including which procedures require consent, from whom consent is obtained, and how that consent should be documented (Table 6.1B). In addition, the standard sets forth those elements that constitute a complete informed consent. Other organizations, notably the American College of Surgeons (Table 6.1C) and the American Medical Association (Table 6.1D) have also issued statements regarding principles of proper informed consent. Each of the statements is roughly congruent with the others on which elements are to be included. The American Medical Association statement also requires that alternatives must be discussed without regard to cost, or inclusion as a covered benefit in a given health plan.

6.8 Conclusions

Historically, ethically and legally, patient autonomy has supplanted physician beneficence as a primary principle

Table 6.1 Elements of informed consent

A. Centers for Medicare and Medicaid Services[a]
A properly executed informed consent form for the operation must be in the patient's chart before surgery, except in emergencies.
A well-designed informed consent process would include discussion of the following elements:
1. A description of the proposed surgery, including the anesthesia to be used;
2. The indications for the proposed surgery;
3. Material risks and benefits for the patient related to the surgery and anesthesia, including the likelihood of each, based on the available clinical evidence, as informed by the responsible practitioner's clinical judgment. Material risks could include risks with a high degree of likelihood but a low degree of severity, as well as those with a very low degree of likelihood but high degree of severity;
4. Treatment alternatives, including the attendant material risks and benefits;
5. The probable consequences of declining recommended or alternative therapies;
6. Who will conduct the surgical intervention and administer the anesthesia;
7. Whether physicians other than the operating practitioner, including but not limited to residents, will be performing important tasks related to the surgery, in accordance with the hospital's policies. Important surgical tasks include: opening and closing, dissecting tissue, removing tissue, harvesting grafts, transplanting tissue, administering anesthesia, implanting devices and placing invasive lines.
B. The Joint Commission[b]
1. The nature of the proposed care, treatment, services, medications, interventions, or procedures
2. Potential benefits, risks, or side effects, including potential problems related to recuperation
3. The likelihood of achieving care, treatment and service goals
4. Reasonable alternatives to the proposed case, treatment, and service goals
5. The relevant risks, benefits, and side effects related to alternatives, including the possible results of not receiving care, treatment, and services
6. When indicated, any limitations on the confidentiality of information learned from or about the patient
C. American College of Surgeons[c]
1. The nature of the illness and the natural consequences of no treatment.
2. The nature of the proposed operation, including the estimated risks of mortality and morbidity.
3. The more common known complications, which should be described and discussed. The patient should understand the risks as well as the benefits of the proposed operation. The discussion should include a description of what to expect during the hospitalization and post hospital convalescence.
4. Alternative forms of treatment, including non-operative techniques.
D. American Medical Association
1. The patient's diagnosis, if known;
2. The nature and purpose of a proposed treatment or procedure;
3. The risks and benefits of a proposed treatment or procedure;
4. Alternatives (regardless of their cost or the extent to which the treatment options are covered by health insurance);
5. The risks and benefits of the alternative treatment or procedure; and
6. The risks and benefits of not receiving or undergoing a treatment or procedure.

[a] http://www.cms.hhs.gov/SurveyCertificationGenInfo/downloads/SCLetter07–17.pdf
[b] The Joint Commission. 2007 Comprehensive Accreditation Manual for Hospitals: The Official Handbook. Oak Brook: Joint Commission Resources, 2007
[c] American College of Surgeons. Statements on Principles. II. Relation of the Surgeon to the Patient. A. Informed Consent. http://www.facs.org/fellows_info/statements/stonprin.html#anchor171960 (Accessed 11/30/2008)
[d] American Medical Association. Professional Resources. Informed Consent. http://www.ama-assn.org/ama/pub/category/4608.html (Accessed 11/30/2008)

guiding the doctrine of informed consent. However, the principles of autonomy and beneficence should be co-equal, and any decisions resulting in patient choice should be shared between patient and surgeon. Required elements of any consent discussion about individual procedures have been developed in case law, statutes, and regulations. Although generally congruent, physicians are advised to check with counsel to be sure their

consent discussions meet all applicable requirements. In the future, non-procedural information, such as financial considerations and individual physician performance will assume greater importance.

References

1. Stetson HG, Moran JE. Malpractice suits, their cause and prevention. *New Engl J Med* 1934; **210**: 1383–4.
2. The National Commission for the Protection of Human Subjects of Biomedical Research. The Belmont Report: Ethical Principles and Guidelines for the Protection of Human Subjects or Research. April 18, 1979. http://ohsr.od.nih.gov/guidelines/belmont.html
3. Meisel A. The "exceptions" to the informed consent doctrine: Striking a balance between competing values in medical decision making. *Wisconsin Law J* 1979; **413**: 434–69.
4. Wilde ML. Bioethical and legal implications of pediatric gastric bypass. *Willamette Law Rev* 2004; **40**: 575–625.
5. Lidz C, Appelbaum P, Meisel A. Two models of implementing informed consent. *Arch Intern Med* 1988; **148**: 1385–9.
6. Burger I, Schill K, Goodman S. Disclosure of individual surgeon's performance rates during informed consent: ethical and epistemological considerations. *Ann Surg* 2007; **245**: 507–13.
7. Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. *N Engl J Med* 2003; **349**: 2117–27.

Chapter 7

Pre-operative surgical management

Basil M. Yurcisin and Eric J. DeMaria

7.1 Introduction

In 2006 the World Health Organization estimated that 1.6 billion adults worldwide were overweight (BMI ≥ 25–29.9 kg m^{-2}) and more than 400 million were obese (BMI ≥ 30 kg m^{-2}) [1]. By the year 2015 these numbers are expected to increase to 2.3 billion and over 700 million, respectively. In the United States 61% of adults (>20 years) are overweight or obese and 4.8% have a BMI ≥ 40 kg m^{-2} [2, 3]. This worldwide epidemic is increasing steadily over all ages, genders, and ethnic groups, and is on the rise in low and middle income countries, once thought to be exempt from inclusion in this discussion [1]. Bariatric surgery has emerged as a safe and effective method of treating extreme obesity [4].

The pre-operative assessment of candidates for bariatric procedures is based on the principle of identifying modifiable health concerns and implementing risk reducing treatments to reduce peri-operative morbidity and mortality. Therefore, the need to understand the proper methods to evaluate obese patients for this elective, but life-saving, surgery becomes more important.

The initial evaluation should begin with a candid discussion between the surgeon and the patient. Bariatric surgery carries significant risks and can fail with no improvement in health and no reduction in the weight of the patient. The patient should also take part in a pre-operative seminar outlining expectations in regards to post-operative recovery, diet alterations, activity, and clinical outcomes [5] (see Chapter 23). Beneficial outcomes are only achieved consistently with careful patient selection and pre-operative planning [6, 7]. In order to properly evaluate the potential bariatric patient, surgeons should ideally have the assistance of a multidisciplinary team including nutritionists, psychologists / psychiatrists, and appropriate medical specialty consultants, as needed (Figure 7.1) [5].

Despite major advances in safety and efficacy data, there has been no change in the National Institutes of Health's Consensus Development Conference Panel patient selection criteria since 1991. These criteria include: BMI ≥ 40 kg m^{-2} or ≥ 35 kg m^{-2} with co-morbid conditions (hypertension, type 2 diabetes mellitus [T2D], heart failure or obstructive sleep apnea [OSA]), documented failure of non-surgical weight loss attempts, and a patient who is compliant, motivated, and well informed [8]. In addition third-party payers frequently impose further requirements, often without compelling evidence of their value, and these can have a significant impact on selection of patients for these procedures. Clinicians evaluating candidates for bariatric surgery need to be aware of these factors.

7.2 Evaluation

7.2.1 Environment

Creating a comfortable environment for obese patients will have a positive impact on their overall experience. Handicap parking and a waiting room with sturdy, armless chairs are important. Examination rooms equipped to accommodate this special needs population should provide extra large doors and furniture, large blood pressure cuffs, space for wheelchairs, oversized gowns, and low-height hydraulic tables [9].

7.2.2 History and physical examination

The initial assessment of the obese patient begins with a detailed history and physical examination, and baseline laboratory studies followed by appropriate specialty consultation. Most bariatric patients have known conditions, which are already being treated by a primary care physician (PCP), alleviating the need to perform additional probing tests.

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

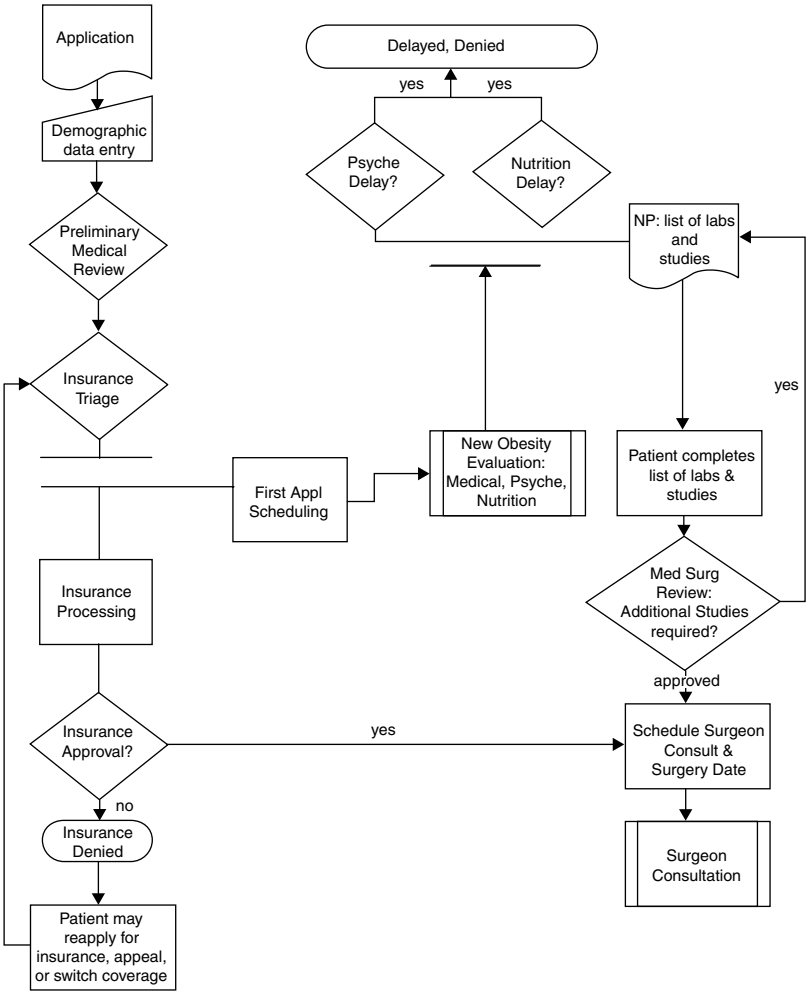

Figure 7.1 Example of a pre-operative workflow

Ramaswamy *et al*. prospectively studied 193 obese patients (mean age of 42 ± 10 years) being evaluated for bariatric surgery. More than half had hypertension, a third had OSA, and one in four had T2D, all of which were being treated by their PCP [10].

Having a patient fill out a comprehensive health questionnaire and performing a history and physical examination with special attention to the co-morbidities of obesity will direct laboratory testing and pre-operative intervention. Factors that increase surgical risk include a history of thromboembolism, smoking, coronary artery disease (CAD), OSA, and super-obesity (BMI > 50 kg m^{-2}) [11]. Super-obesity, male gender, hypertension (HTN), age (≥ 45 years), and risk factors for pulmonary embolism (previous thromboembolism, pre-operative vena cava filter, and pulmonary hypertension) have also been found to be predictive of increased peri-operative risk [12].

The surgical candidate's history should include behavioral (previous weight loss efforts, dietary style, and physical activity), cognitive/emotional (expectations, psychiatric illness, and eating disorder), developmental (age of onset, family history, and co-morbidities), current life situation, motivation, and expectations information.

Secondary causes of obesity should be considered. Physicians should search for markers of hypothyroidism or Cushing syndrome, and be aware of any medications that could promote weight gain. A social history that documents smoking, alcohol, or substance abuse, and social environment, may yield issues to be resolved prior to operative intervention [5, 8, 9].

Table 7.1 Suggested pre-operative laboratory tests

Complete blood count
Comprehensive metabolic panel
Hemoglobin A1c
Ferritin
Thyroid stimulating hormone
Lipid profile
Barium swallow
Electrocardiogram

Vital signs including blood pressure, heart rate, room air oxygen saturation, weight, and height should be documented. The calculated BMI and waist circumference are predictors of co-morbid disease. A waist circumference of ≥ 35 inches in women and ≥ 40 inches in men is associated with an increased risk of metabolic disease and CAD. Increased BMI also correlates with the risk of CAD [8] (Table 7.1). Signs of right or left ventricular dysfunction, congestive heart failure, metabolic disorders, and pulmonary disease should be noted.

Laboratory tests should be ordered in response to specific findings in the history and physical. Appropriate pre-operative laboratory studies can identify patients with risk factors for CAD (diabetes, dyslipidemia, and the metabolic syndrome), nutritional deficiencies, and metabolic complications of obesity. Sleep studies and ECG are recommended for obese patients being evaluated for bariatric surgery [13, 14]. In the presence of a significant cardiac or pulmonary history or ECG abnormality obtaining an echocardiogram, spirometry, and arterial blood gases are recommended [13]. A chest x-ray is indicated in patients > 60 years or patients with suspected heart or lung disease [15] (Table 7.2).

Exercise tolerance should be assessed. Patients with unlimited exercise tolerance have half the risk of serious post-operative complications compared to those with a low tolerance. Poor tolerance is defined as inability to walk four blocks or climb two flights of stairs without pulmonary, cardiac, or vascular symptoms [16, 17]. Candidates with poor exercise tolerance, ECG abnormalities, or signs/symptoms of heart disease should be considered for possible functional cardiac evaluation.

7.2.2.1 Cardiac

Symptoms such as angina, palpitations, orthopnea, and paroxysmal nocturnal dyspnea are evidence of altered cardiac functional status. An abnormal ECG is an independent predictor of a complicated post-operative course, which is defined as requiring ≥ 48 hrs of intensive care unit (ICU) admission or transfer to the ICU from the floor [18]. The American College of Cardiology and the American Heart Association recommend that candidates for bariatric surgery should have an ECG based on age or concomitant medical illnesses [16], although it is our practice to obtain an ECG for all our patients.

Table 7.2 Correlated CAD risk with increasing BMI

	BMI (kg m^{-2})	CAD risk
Underweight	<18.5	Increased
Normal	18.5–24.9	Normal
Overweight	25.0–29.9	Increased
Obesity	30.0–34.9	High
	35.0–39.9	Very high
Extreme obesity	≥40.0	Extremely high

CAD, coronary arterial disease.
Additional adiposity-related risk factors: waist circumference 40 inches (men) and 35 inches (women); weight gain of ≥5 kg since age 18–20 years.
Modified from: Ref [9].

Patients referred to a cardiologist for evaluation due to suspicion of CAD should undergo an exercise echocardiogram [19]. The dobutamine stress echocardiogram is an acceptable alternative for patients who cannot endure treadmill testing [20]. Obesity, previous cardiac surgery, chronic obstructive pulmonary disease, and increased age are causes of inadequate visualization during trans-thoracic echocardiography in as many as 30% of such patients [21]. The use of trans-esophageal echocardiography may resolve this problem, but has a questionable safety profile [22]. When properly evaluated and treated by a cardiologist, patients with known CAD have no increase in major peri-operative mortality and cardiac complications following bariatric surgery [23].

7.2.2.2 Pulmonary

Excessive weight infringes on the chest wall, rib cage, and diaphragm, directly affecting pulmonary function in MO patients. In addition, OSA, and obesity hypoventilation syndrome (OHS) are associated with obesity [9] (see Chapter 2). Both OSA and OHS can be improved by pre-operative continuous positive airway pressure (CPAP) therapy. When untreated both these conditions may cause apnea in response to anesthetic drugs [24]. Undiagnosed or poorly treated OSA has an unknown impact on bariatric surgical peri-operative morbidity and mortality [25]. Any patient with a high index of suspicion for OSA should undergo polysomnography [13]. According to the American Society of

Anesthesiologists, patients with OSA should be placed on CPAP throughout the peri-operative period. The presence of signs or symptoms of OSA, even without diagnosis, is adequate cause to begin CPAP treatment [26]. Airway management is a critical concern (see Chapters 9 and 12). During surgery appropriate positioning and preoxygenation are mandatory [27].

7.2.2.3 Hypercoagulability

Increased intra-abdominal pressure secondary to obesity creates a state of chronic abdominal compartment syndrome. This in turn reduces venous return from the legs and is responsible for venous stasis. The pneumoperitoneum during laparoscopic surgery further exacerbates intra-abdominal pressure, and the peri-operative rise in circulating pro-coagulable factors increases the risk of venous thromboembolism (VTE). Although most bariatric surgeons employ prophylactic use of anticoagulation, there are no agreed upon dosing guidelines. Pre-operative placement of an inferior vena cava filter may be beneficial in those at high risk for post-operative VTE (venous stasis disease, BMI $\geq$ 60 kg m^{-2}, truncal obesity, prior VTE, and known hypercoagulable state). Pre-operative subcutaneous heparin, OR enoxaprin, sequential compression boots, and early ambulation seem to be the best strategies to combat VTE. Patients with elevated risk of VTE should have extended prophylaxis with enoxaprin for 10 days post-operatively [4].

7.2.2.4 Gastrointestinal

Pre-operative endoscopy is reserved for patients with complaints of reflux, dyspepsia, or dysphagia. In Europe, current guidelines advocate pre-operative endoscopy in all patients, regardless of symptoms [28]. Many bariatric procedures render the remnant stomach inaccessible to traditional endoscopy so the threshold for investigating the upper gastrointestinal (UGI) system should be low. Endoscopy may influence the choice of surgical procedure being recommended for the patient with reflux, hiatial hernia, or ulcer [28, 29, 30]. Obesity is known to be associated with higher risk of reflux, erosive esophagitis, and esophageal adenocarcinoma [31]. Contrast-enhanced radiologic studies may provide an alternative approach to investigation [32] and is performed in nearly all our patients. The American Society for Gastrointestinal Endoscopy has recommended *Helicobacter pylori* screening and treatment of positive individuals before bariatric surgery in order to reduce the incidence of marginal ulcer as a complication of gastric bypass [33]. This recommendation is considered controversial among bariatric surgeons.

The most common cause of elevated liver function tests (LFTs) in the bariatric patient is non-alcoholic fatty liver disease (NAFLD), which can progress to cirrhosis (see Chapter 3). For a patient with elevated LFTs, ultrasound or computed tomography (CT) may be indicated to determine presence of cirrhosis or portal hypertension [34]. Bariatric surgery may have a favorable effect on steatosis, but the value is not definitive [35, 36).

Rapid weight loss in patients with known gallbladder dysfunction can trigger development of symptomatic complaints. Pre-operative work-up with ultrasound is warranted in this population, although controversy exists as to the need for prophylactic cholecystectomy [37]. If the gallbladder is not removed, post-operative treatment for 6 months with ursodial may prevent symptomatic events [38].

7.2.2.5 Psychiatric

Although psychiatric evaluation for patients seeking bariatric surgery is considered important, at the present time there is a lack of consensus as to how to proceed. In many centers, the psychiatric interview is required but often lacks standardization. It is believed that approximately half of patients referred to bariatric surgeons have psychiatric issues that should be addressed prior to surgery or require psychotropic medications [39, 40].

In a study of 500 patients over a 2-year-period, the most common reasons for a negative recommendation for surgery were overeating to cope with stress or emotional distress, current eating disorder, uncontrolled psychopathology, and the presence of significant life stressors [41]. Binge eating, personality disorders, and untreated/undertreated depression warrant delay for treatment prior to surgery [42]. Personality disorders and severe psychiatric disorders requiring admission for inpatient treatment are predictors of poor outcomes [43]. Collazo-Clavell *et al.* require the absence of psychiatric hospitalization, abstinence from substance abuse for 1 year, and ongoing licensed-provider treatment for any existing psychiatric issues before proceeding with surgery [44]. The appropriately managed psychiatric patient can have acceptable outcomes [45].

7.2.2.6 Nutritional

Nutritional evaluation should also be initiated prior to surgery. The American Society of Metabolic and Bariatric Surgery states that the pre-operative nutritional assessment should be conducted by a qualified professional to identify the patient's nutritional and educational needs [46]. Adherence to outlined

pre-operative behavioral changes, especially with respect to exercise and dietary restrictions, has been shown to improve long-term outcomes following bariatric surgery [47]. The bariatric candidate needs to be reminded of the importance of following a prescribed diet, taking lifelong dietary supplements, and following an exercise regimen.

Participation and success (5–10% weight lost) in a pre-operative weight loss program may be associated with a less technically difficult operation and better post-operative weight loss at 3 months. However, pre-operative weight loss has not been shown to impact the incidence of complications or resolution of co-morbidities, and a mandate for the patient to lose weight pre-operatively may cause an unnecessary delay in surgery [48].

7.3 Risk and contraindications

In 2007, DeMaria *et al*. suggested a risk stratification tool for bariatric patients [49]. The Obesity Surgery – Mortality Risk Score (OS-MRS) assigns one point to each of five pre-operative variables: BMI ≥ 50 kg m^{-2}, male gender, HTN, pulmonary embolic risk factors, and age ≥ 45 years. A score of 0 to 1 is classified as 'A', 2 to 3 as 'B', and 4 to 5 as 'C' with associated mortality risks of 0.2, 1.1, and 2.4%, respectively [49]. This system was later validated by a multi-center study of more than 4000 patients [12].

Risk of complications and death has further been linked to the expertise of the surgeon. Fernandez *et al*. reported an overall leak rate of 6.8% in their first 102 laparoscopic gastric bypass (LGB) operations, followed by a reduction to 1.8% over the next 164 [50]. Maher *et al*. recently reported continued reduction in adverse outcomes for experienced surgeons performing LGB in a series of 450 consecutive procedures, with no leak or mortality over the final year of their study [51].

Absolute contraindications for bariatric surgery are few. Lack of understanding of the procedure and its risks, severe liver disease with portal hypertension, and unstable or terminal illness are considered contraindications [44]. In general, the very old (> 65 years) and very young (< 21 years) may not be considered good candidates for surgery, although such arbitrary barriers to treatment are being reconsidered over time. In particular, barriers to adolescent gastric bypass are rapidly falling because of studies showing sustained weight loss, co-morbidity resolution, and improved self-image in these patients [52] (see Chapter 24). Super-super-obese patients (> 400 pounds) may be denied surgical intervention on the basis of higher surgical risk. On occasion, such patients are denied on the basis that they are too large for radiologic imaging equipment (particularly CT scanners) in many hospitals. This is unfortunate as such denial clearly has a negative impact by excluding such end-stage MO individuals from the only treatment for severe obesity proven to be durable.

7.4 Summary

Appropriate evaluation of the bariatric patient seeks to identify modifiable risk factors and can exclude poor candidates prior to surgery. Patient evaluation is enhanced by a multidisciplinary team approach to identify and treat potential problems. After initial discussion with the patient to explain realistic expectations, the medical work-up should generate appropriate sub-specialty consultation with the goal of readying the patient for surgery. Application of the risk scoring system (OS-MRS) identifies patients who are at greater risk for a poor outcome after surgery, allowing for more accurate informed consent discussions and more thorough pre-surgery evaluation in higher risk patients. Although life-saving for the vast majority of MO patients, bariatric surgery may not be appropriate in patients with poor cognitive ability who cannot follow direction and therefore may become a danger to themselves, in those with unstable psychiatric illness, portal hypertension from severe liver disease, poorly controlled CAD, or cancer with a poor life expectancy.

References

1. World Health Organization: Obesity. Fact sheet No 311, September 2006.
2. Kuczmarski RJ, Carroll MD, Flegal KM, Troiano RP. Varying body mass index cutoff points to describe overweight prevalence among U.S. adults: NHANES III (1988 to 1994). *Obes Res* 1997; **5**: 542–8.
3. Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006; **295**: 1549–55.
4. Kuruba R, Koche LS, Murr MM. Preoperative assessment and perioperative care of patients undergoing bariatric surgery. *Med Clin North Am*2007 May; **91**(3):339–51, ix.
5. Buchwald H. Bariatric surgery for morbid obesity: health implications for patients, health professionals, and third-party payers. *J Am Coll Surg* 2005; **200**: 593–604.
6. Collazo-Clavell ML. Safe and effective management of the obese patient. *Mayo Clin Proc* 1999; **74**: 1255–9.

7. Cowan GS, Jr, Hiler ML, Buffington C. Criteria for selection of patients for bariatric surgery. *Eur J Gastroenterol Hepatol* 1999; **11**: 69–75.
8. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults – The Evidence Report. National Institutes of Health. *Obes Res* 1998; **6** (Suppl 2): 51S-209S.
9. Klein S, Burke LE, Bray GA, *et al*. Clinical implications of obesity with specific focus on cardiovascular disease: a statement for professionals from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. *Circulation* 2004; **110**: 2952–67.
10. Ramaswamy A, Gonzalez R, Smith CD. Extensive preoperative testing is not necessary in morbidly obese patients undergoing gastric bypass. *J Gastrointest Surg* 2004; **8**:159–64; discussion 64–5.
11. Ballantyne GH, Svahn J, Capella RF, *et al*. Predictors of prolonged hospital stay following open and laparoscopic gastric bypass for morbid obesity: body mass index, length of surgery, sleep apnea, asthma, and the metabolic syndrome. *Obes Surg* 2004; **14**: 1042–50.
12. DeMaria EJ, Murr M, Byrne TK, *et al*. Validation of the obesity surgery mortality risk score in a multicenter study proves it stratifies mortality risk in patients undergoing gastric bypass for morbid obesity. *Ann Surg* 2007; **246**: 578–82; discussion 83–4.
13. Catheline JM, Bihan H, Le Quang T, *et al*. Preoperative cardiac and pulmonary assessment in bariatric surgery. *Obes Surg* 2008; **18**: 271–7.
14. O'Keeffe T, Patterson EJ. Evidence supporting routine polysomnography before bariatric surgery. *Obes Surg* 2004; **14**: 23–6.
15. Smetana GW, Macpherson DS. The case against routine preoperative laboratory testing. *Med Clin North Am* 2003; **87**: 7–40.
16. Eagle KA, Brundage BH, Chaitman BR, *et al*. Guidelines for perioperative cardiovascular evaluation for noncardiac surgery. Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Committee on Perioperative Cardiovascular Evaluation for Noncardiac Surgery. *Circulation* 1996; **93**: 1278–317.
17. Reilly DF, McNeely MJ, Doerner D, *et al*. Self-reported exercise tolerance and the risk of serious perioperative complications. *Arch Intern Med* 1999; **159**: 2185–92.
18. Gonzalez R, Bowers SP, Venkatesh KR, Lin E, Smith CD. Preoperative factors predictive of complicated postoperative management after Roux-en-Y gastric bypass for morbid obesity. *Surg Endosc* 2003; **17**: 1900–4.
19. Gibbons RJ, Balady GJ, Bricker JT, *et al*. ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). *Circulation* 2002; **106**: 1883–92.
20. Bhat G, Daley K, Dugan M, Larson G. Preoperative evaluation for bariatric surgery using transesophageal dobutamine stress echocardiography. *Obes Surg* 2004; **14**: 948–51.
21. Vitarelli A, Dagianti A, Conde Y, Penco M, Pastore LR, Fedele F. Value of transesophageal dobutamine stress echocardiography in assessing coronary artery disease. *Am J Cardiol* 2000; **86**: 57G–60G.
22. Frohwein S, Klein JL, Lane A, Taylor WR. Transesophageal dobutamine stress echocardiography in the evaluation of coronary artery disease. *J Am Coll Cardiol* 1995; **25**: 823–9.
23. Lopez-Jimenez F, Bhatia S, Collazo-Clavell ML, Sarr MG, Somers VK. Safety and efficacy of bariatric surgery in patients with coronary artery disease. *Mayo Clin Proc* 2005; **80**: 1157–62.
24. Qaseem A, Snow V, Fitterman N, *et al*. Risk assessment for and strategies to reduce perioperative pulmonary complications for patients undergoing noncardiothoracic surgery: a guideline from the American College of Physicians. *Ann Intern Med* 2006; **144**: 575–80.
25. Fernandez AZ, Jr, Demaria EJ, Tichansky DS, *et al*. Multivariate analysis of risk factors for death following gastric bypass for treatment of morbid obesity. *Ann Surg* 2004; **239**: 698–702; discussion 703.
26. Gross JB, Bachenberg KL, Benumof JL, *et al*. Practice guidelines for the perioperative management of patients with obstructive sleep apnea: a report by the American Society of Anesthesiologists Task Force on Perioperative Management of Patients with Obstructive Sleep Apnea. *Anesthesiology* 2006; **104**: 1081–93.
27. Dixon BJ, Dixon JB, Carden JR, *et al*. Preoxygenation is more effective in the 25 degrees head-up position than in the supine position in severely obese patients: a randomized controlled study. *Anesthesiology* 2005; **102**: 1110–5; discussion 5A.
28. Sauerland S, Angrisani L, Belachew M, *et al*. Obesity surgery: evidence-based guidelines of the European Association for Endoscopic Surgery (EAES). *Surg Endosc* 2005; **19**: 200–21.
29. Greenstein RJ, Nissan A, Jaffin B. Esophageal anatomy and function in laparoscopic gastric restrictive bariatric surgery: implications for patient selection. *Obes Surg* 1998; **8**: 199–206.
30. Schirmer B, Erenoglu C, Miller A. Flexible endoscopy in the management of patients undergoing Roux-en-Y gastric bypass. *Obes Surg* 2002; **12**: 634–8.
31. Hampel H, Abraham NS, El-Serag HB. Meta-analysis: obesity and the risk for gastroesophageal reflux

disease and its complications. *Ann Intern Med* 2005; **143**: 199–211.

32. Frigg A, Peterli R, Zynamon A, Lang C, Tondelli P. Radiologic and endoscopic evaluation for laparoscopic adjustable gastric banding: preoperative and follow-up. *Obes Surg* 2001; **11**: 594–9.
33. Anderson MA, Gan SI, Fanelli RD, *et al*. Role of endoscopy in the bariatric surgery patient. *Gastrointest Endosc* 2008; **68**: 1–10.
34. Siegelman ES, Rosen MA. Imaging of hepatic steatosis. *Semin Liver Dis* 2001; **21**: 71–80.
35. Dallal RM, Mattar SG, Lord JL, *et al*. Results of laparoscopic gastric bypass in patients with cirrhosis. *Obes Surg* 2004; **14**: 47–53.
36. Kral JG, Thung SN, Biron S, *et al*. Effects of surgical treatment of the metabolic syndrome on liver fibrosis and cirrhosis. *Surgery* 2004; **135**: 48–58.
37. Villegas L, Schneider B, Provost D, *et al*. Is routine cholecystectomy required during laparoscopic gastric bypass? *Obes Surg* 2004; **14**: 206–11.
38. Sugerman HJ, Brewer WH, Shiffman ML, *et al*. A multicenter, placebo-controlled, randomized, double-blind, prospective trial of prophylactic ursodiol for the prevention of gallstone formation following gastric-bypass-induced rapid weight loss. *Am J Surg* 1995; **169**: 91–6; discussion 6–7.
39. Pawlow LA, O'Neil PM, White MA, Byrne TK. Findings and outcomes of psychological evaluations of gastric bypass applicants. *Surg Obes Relat Dis* 2005; **1**: 523–7; discussion 8–9.
40. Rosik CH. Psychiatric symptoms among prospective bariatric surgery patients: rates of prevalence and their relation to social desirability, pursuit of surgery, and follow-up attendance. *Obes Surg* 2005; **15**: 677–83.
41. Zimmerman M, Francione-Witt C, Chelminski I, *et al*. Presurgical psychiatric evaluations of candidates for bariatric surgery, part 1: reliability and reasons for and frequency of exclusion. *J Clin Psychiatry* 2007; **68**: 1557–62.
42. van Hout GC, Verschure SK, van Heck GL. Psychosocial predictors of success following bariatric surgery. *Obes Surg* 2005; **15**: 552–60.
43. Herpertz S, Kielmann R, Wolf AM, Hebebrand J, Senf W. Do psychosocial variables predict weight loss or mental health after obesity surgery? A systematic review. *Obes Res* 2004; **12**: 1554–69.
44. Collazo-Clavell ML, Clark MM, McAlpine DE, Jensen MD. Assessment and preparation of patients for bariatric surgery. *Mayo Clin Proc* 2006; **81**(10 Suppl): S11–7.
45. Clark MM, Balsiger BM, Sletten CD, *et al*. Psychosocial factors and 2-year outcome following bariatric surgery for weight loss. *Obes Surg* 2003; **13**: 739–45.
46. Aills L, Blankenship J, Buffington C, Furtado M, Parrott J. ASMBS Allied Health Nutritional Guidelines for the Surgical Weight Loss Patient. *Surg Obes Relat Dis* 2008; **4**(5 Suppl): S73–108.
47. Cottam DR, Atkinson J, Anderson A, Grace B, Fisher B. A case-controlled matched-pair cohort study of laparoscopic Roux-en-Y gastric bypass and lap-band patients in a single US center with three-year follow-up. *Obes Surg* 2006; **16**: 534–40.
48. Tarnoff M, Kaplan LM, Shikora S. An evidenced-based assessment of preoperative weight loss in bariatric surgery. *Obes Surg* 2008; **18**: 1059–61.
49. DeMaria EJ, Portenier D, Wolfe L. Obesity surgery mortality risk score: proposal for a clinically useful score to predict mortality risk in patients undergoing gastric bypass. *Surg Obes Relat Dis* 2007; **3**: 134–40.
50. Fernandez AZ, Jr., DeMaria EJ, Tichansky DS, *et al*. Experience with over 3,000 open and laparoscopic bariatric procedures: multivariate analysis of factors related to leak and resultant mortality. *Surg Endosc* 2004; **18**: 193–7.
51. Maher JW, Hawver LM, Pucci A, Wolfe LG, Meador JG, Kellum JM. Four hundred-fifty consecutive laparoscopic Roux-en-Y gastric bypasses with no mortality and declining leak rates and lengths of stay in a bariatric training program. *J Am Coll Surg* 2008; **206**: 940–4; discussion 4–5.
52. Treadwell JR, Sun F, Schoelles K. Systematic review and meta-analysis of bariatric surgery for pediatric obesity. *Ann Surg* 2008; **248**: 763–76.

Chapter 8

Pre-operative management: nutritionist/psychologist/internist

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8.1 Introduction

As the prevalence of obesity increases worldwide, so has the number of bariatric surgical procedures [1, 2]. In select patients, bariatric surgery has been shown to be an effective means to long-term weight loss and improvement in weight related medical co-morbidities [3, 4]. Since bariatric surgery is not without risk, and still requires lifelong lifestyle modification for successful weight loss maintenance, appropriate selection of patients is important to achieve optimal results. The evaluation process for bariatric surgery needs to be multidisciplinary with evaluation and optimization of physical and mental health, as well as identification of prior obstacles for successful weight loss. This typically takes a team of professionals including physician nutrition specialists, dietitians, psychologists/psychiatrists, physical therapists, and surgeons.

8.2 Criteria

The National Institutes of Health Consensus Development Conference outlined criteria for identifying appropriate candidates for bariatric surgery [5]. BMI criteria serve as a cornerstone for these recommendations, with a BMI $\geq 40\ kg\ m^{-2}$ or $\geq 35\ kg\ m^{-2}$ with co-morbid conditions being recommended for consideration of bariatric surgery. Patients should have documented failure of non-surgical weight loss efforts and should be well informed, compliant, and motivated. There should be no medical and psychological contraindications present [5–10]. Frequently, additional criteria may need to be fulfilled prior to third party payer approval.

8.3 Medical assessment

Prior to evaluating patients with obesity for bariatric surgery, it is important to provide an environment where these patients can feel comfortable. That includes armless chairs, scales capable of weighing heavier patients, large gowns, and large blood pressure cuffs.

A detailed weight history should include weight trends, inciting factors/events that lead to weight changes (e.g., pregnancy, depression, medical illness, etc.), as well as current dietary and physical activity/exercise habits. Previous weight loss efforts including amount of weight lost, duration of weight maintenance, and factors contributing to weight regain should be reviewed and documented. Perceived obstacles for successful weight loss and weight loss maintenance should also be reviewed and can serve as an area of focus prior to bariatric surgery [6, 11].

The dietitian serves as an invaluable part of the team by evaluating a patient's dietary habits and educating the prospective surgical candidate on dietary changes required after bariatric surgery. Reviewing food records with subsequent detailed dietary analysis and ongoing advice on dietary changes are key aspects of the medical weight loss program that should be a part of the pre-bariatric surgery program.

The evaluation for weight related co-morbidities should include the assessment of hyperglycemia or type 2 diabetes mellitus (T2D), hyperlipidemia, hypertension, coronary artery disease, non-alcoholic fatty liver disease (NAFLD) and obstructive sleep apnea (OSA). A pre-operative evaluation for medical conditions that increase the risk of peri-operative risk, as well as an evaluation for conditions that may worsen post-operatively, are essential elements of the work-up [12–14] (Table 8.1).

Mortality rates after bariatric surgery are now less than 1% with higher mortality rates having been reported among Medicare recipients [3, 15]. Peri-operative complication risk is higher in men, those older than 45 years, those with extreme obesity (BMI

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Table 8.1 Factors that may increase surgical risk

Factors that increase risk of peri-operative complications
Extreme obesity (BMI >50 kg m^{-2})
Tobacco abuse
Obstructive sleep apnea
Uncompensated coronary artery disease and/or congestive heart failure
History of thromboembolic disease
Medical conditions/diseases that potentially worsen or develop after bariatric surgery
Cholelithiasis
Nutritional deficiencies (iron, vitamin B_{12}, vitamin D, etc.)
Hyperoxaluric nephrolithiasis
Post-prandial hypoglycemia/hyperinsulinemic hypoglycemia with nesidioblastosis

>50 kg m^{-2}), and patients who have weight-related co-morbidities including hypertension, T2D, OSA, asthma, and/or risk factors for pulmonary embolism and cirrhosis [12, 16, 17]. Pre-operative assessment and medical management therefore need to focus on improvement of modifiable risks including achieving optimal glycemic control, and appropriate treatment of OSA/hypopnea, etc. [18, 19]. Pre-operative symptomatic gallbladder disease should be further evaluated with radiologic imaging since the risk of gallbladder disease may increase with rapid weight loss. This can help the surgeon determine pre-operatively whether a particular patient should have a cholecystectomy during bariatric surgery [13, 20].

Abnormal liver function tests should lead to further evaluation to clarify underlying pathology. A liver biopsy is the gold standard for diagnosis. Non-alcoholic liver disease is prevalent in obese patients, and although steatosis typically improves with post-operative weight loss, cirrhosis may actually worsen [17, 21–24]. Portal hypertension is a common contraindication to several bariatric surgical procedures. Hyperoxaluric nephrolithiasis risk increases after Roux-en-Y gastric bypass (RYGB) [25, 26] and therefore symptomatic individuals, or those with a history of nephrolithiasis should be screened pre-operatively. Hyperinsulinemic hypoglycemia (nesidioblastosis), which usually presents as post-prandial hypoglycemia, has been reported after RYGB [27].

Evaluation for secondary causes of obesity is also a key component of the initial evaluation. Screening for hypothyroidism is recommended [28]. Cushing's syndrome is a rare condition that should be screened for only in patients where there is strong clinical suspicion. An evaluation for physical limitations to physical activity should also be undertaken and appropriate referral to physical medicine and rehabilitation, sports medicine, or orthopedics should be made. Family history of obesity and weight-related co-morbidities should be documented. Social history should include information about tobacco, alcohol, and illicit drug use.

Vital signs, including blood pressure, pulse rate, height, and weight, should be recorded and BMI calculated. Waist circumference can be measured as well since it adds additional information with regards to health risk [6], although it may be a less helpful tool in people whose BMI > 40 kg m^{-2}. The physical exam should focus on evaluating for weight-related complications as well as signs of secondary causes of obesity like hypothyroidism and hypercortisolism. Pre-operative labs and tests should be completed in keeping with the goals of identifying weight-related complications, conditions that increase peri-operative risk and conditions that can worsen post-operatively [14, 29] (Table 8.2).

There are few absolute medical contraindications for bariatric surgery. The presence of mental and/or psychologic impairment that limits the ability to understand and consent to surgery is definitely one of them. Advanced liver disease with portal hypertension is a contraindication for most types of bariatric surgery. Medical conditions that increase peri-operative risk to an unacceptable level, like unstable coronary disease, would be considered a contraindication. Older age is not an absolute contraindication. Additional contraindications specific for laparoscopic adjustable gastric banding (LAGB) include inflammatory bowel disease, chronic pancreatitis, autoimmune connective tissue disease (including family history), and severe esophageal varices.

8.4 Psychologic assessment

A psychologic assessment is an integral part of the evaluation of the patient seeking bariatric surgery, yet no consensus exists regarding necessary components of the evaluation. For most bariatric surgery programs, the psychologic assessment serves to identify factors that may impair an individual's ability to understand or comply with recommendations after bariatric surgery and so might limit their long-term success [14, 30, 31].

There is a high prevalence (50%) of Axis I and II disorders in patients seeking bariatric surgery [32], but for the majority of patients this is not a contraindication to

Table 8.2 Recommended laboratory and additional tests prior to bariatric surgery

Fasting blood glucose
Lipid profile
Electrolytes including sodium, potassium, calcium and phosphorus
Liver function tests, including AST, ALT, total and direct bilirubin
Kidney function tests, including creatinine
Complete blood cell count
Ferritin
Vitamin B_{12}
Thyroid stimulating hormone
25-hydroxyvitamin D level
Electrocardiogram
Especially in men over 45 years old, women over 55 years old, patients with known or suspected heart disease or at high risk for heart disease
Chest x-ray
Especially in patients over 60 years old or with suspected or known lung or heart disease
Additional tests as clinically indicated

AST, aspartate aminotransferase; ALT, alanine aminotranferase.

proceeding with surgery. However, 15–30% of patients may be referred for additional psychiatric treatment prior to bariatric surgery, and up to 10% of these may be denied surgery. Tools used by mental health providers in their assessment vary and often include a structured interview such as the Boston interview for gastric bypass, the Weight and Lifestyle Inventory, the Beck Depression Inventory, and the Minnesota Multiphasic Personality Inventory. Additional treatment is recommended for individuals with active depressive symptoms, personality disorders, trauma history, substance abuse, or maladaptive eating behaviors such as binge-eating disorder and purging. Once well managed, these psychologic difficulties or psychiatric disorders may no longer represent a contraindication to proceeding with surgery. Poor weight loss outcomes have been reported in individuals with serious psychiatric disorders requiring hospitalization and those with personality disorders. Although not considered a contraindication to surgery nor associated with differences in weight loss outcomes, a history of sexual abuse or trauma has been associated with an increased risk for a post-traumatic stress disorder and/or worsening symptoms of depression after surgery [14, 31, 33].

Current illicit drug use, active alcoholism, symptoms of schizophrenia, and severe mental retardation (IQ < 50) [34] are contraindications for bariatric surgery. Lack of knowledge regarding bariatric surgery is a contraindication, however, one that can be easily remedied in the majority of patients.

8.5 Preparation

It is imperative to review expected weight loss outcomes, possible health benefits, and surgical as well as medical risks with the patient so that she/he has realistic expectations. A weight loss of at least 50% of excess body weight would be considered a successful outcome after bariatric surgery [5]. After RYGB this is an expected outcome at approximately 1 year post-operatively, while it may take as long as 3–5 years after LAGB [35, 36]. At 10 years post-operatively, 10–25% of patients who undergo bariatric surgery fail to maintain their weight loss [4, 7]. Factors contributing to poorer weight loss are complex and studies have found varying results.

Non compliance with dietary and physical activity recommendations is associated with worse long-term outcomes [37]. The effect of pre-operative BMI, male gender, larger gastric pouch, and pre-operative diagnosis of diabetes mellitus on long-term outcome is controversial [38–40]. Presurgical weight loss has not been a consistent predictor of post-operative weight loss [40–42]. Older-age, binge eating disorder, sweet-eating behavior, and more severe obesity are associated with poorer outcomes after LAGB [43, 44].

It is evident that patients seeking bariatric surgery have lifestyles incompatible with successful management of their weight. It has been our practice to require our patients to participate in cognitive behavioral therapy in preparation for surgery. To date, there are no published studies reporting the impact of behavioral therapy in bariatric surgery candidates as to weight loss outcomes. Several investigators have reported improved weight loss outcomes with behavioral therapy as a component of a medically supervised weight loss program [45, 46]. Behavioral therapy can provide support and guidance as patients pursue lifestyle changes (eating habits, exercise, stress management, etc.) necessary for long-term success at weight management.

Unfortunately there is little data to help guide the amount and progression of physical activity that we should recommend for our pre-bariatric patients, especially those who are very sedentary and/or have physical limitations because of weight bearing joint pain

and or arthropathy. Our clinical practice is to recommend that they at least increase their physical activity compared to their baseline. A pedometer and physical activity log may help them keep track of their progress. Water/pool activities like swimming or water aerobics are options for those who are unable to easily perform weight-bearing activities like walking. A referral to physical medicine and rehabilitation or sports medicine may be invaluable in evaluating the patients' limitations and developing a physical activity program with them. Many patients who are contemplating bariatric surgery have cardiac risk factors: therefore a cardiac stress test should be considered prior to initiating an exercise program as per the guidelines of the American College of Cardiology and America Heart Association practice guidelines [47].

Tracking non-compliance with pre-operative recommendations often helps identify patients who are unmotivated and who may have poor compliance with dietary, physical activity, and vitamin/mineral supplements post-operatively. This includes patients who cancel or do not present for appointments and consults, or who are not compliant with other treatments like use of continuous positive airway pressure (CPAP) and nicotine cessation. These patients often have their surgery postponed indefinitely.

8.6 Summary

In summary, bariatric surgery is an important tool for the management of the patient with medically complicated obesity. The goals of the medical and psychologic evaluation prior to bariatric surgery are to identify patients who meet the accepted criteria for bariatric surgery, identify, and optimize their current medical and psychologic health, minimize the risk for post-operative complications, and prepare them by providing the tools necessary for long-term success at weight management. There is still much to learn about bariatric surgery, especially how to minimize complications and how to predict success to assure desired long-term outcomes.

References

1. Santry HP, Gillen DL, Lauderdale DS. Trends in bariatric surgical procedures. *JAMA*. 2005; **294**: 1909–17.
2. Steinbrook R. Surgery for severe obesity. *N Engl J Med* 2004; **350**: 1075–9.
3. Buchwald H, Avidor Y, Braunwald E, *et al*. Bariatric surgery: a systematic review and meta-analysis. *JAMA* 2004; **292**: 1724–37.
4. Sjostrom L, Lindroos AK, Peltonen M, *et al*. Lifestyle, diabetes, and cardiovascular risk factors 10 years after bariatric surgery. *N Engl J Med* 2004; **351**: 2683–93.
5. NIH conference. Gastrointestinal surgery for severe obesity. Consensus Development Conference Panel. *Ann Intern Med* 1991; **115**: 956–61.
6. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults – The Evidence Report. National Institutes of Health. *Obes Res* 1998; **6** (Suppl 2): 51S–209S.
7. Balsiger BM, Luque de Leon E, Sarr MG. Surgical treatment of obesity: who is an appropriate candidate? *Mayo Clin Proc* 1997; **72**: 551–7.
8. Collazo-Clavell M. Safe and effective management of the obese patient. *Mayo Clin Proc* 1999; **74**: 1255–60.
9. Cowan GS, Jr., Hiler ML, Buffington C. Criteria for selection of patients for bariatric surgery. *Eur J Gastroenterol Hepatol* 1999; **11**: 69–75.
10. Kim JJ, Tarnoff ME, Shikora SA. Surgical treatment for extreme obesity: evolution of a rapidly growing field. *Nutr Clin Pract* 2003; **18**: 109–23.
11. Buchwald H. Bariatric surgery for morbid obesity: health implications for patients, health professionals, and third-party payers. *J Am Coll Surg* 2005; **200**: 593–604.
12. Ballantyne GH, Svahn J, Capella RF, *et al*. Predictors of prolonged hospital stay following open and laparoscopic gastric bypass for morbid obesity: body mass index, length of surgery, sleep apnea, asthma, and the metabolic syndrome. *Obes Surg* 2004; **14**: 1042–50.
13. Crookes PF. Surgical treatment of morbid obesity. *Ann Rev Med* 2006; **57**: 243–64.
14. Collazo-Clavell ML, Clark MM, McAlpine DE, Jensen MD. Assessment and preparation of patients for bariatric surgery. *Mayo Clin Proc* 2006; **81**(10 Suppl): S11–7.
15. Flum DR, Salem L, Elrod JA, Dellinger EP, Cheadle A, Chan L. Early mortality among Medicare beneficiaries undergoing bariatric surgical procedures. *JAMA* 2005; **294**: 1903–8.
16. Cooney RN, Haluck RS, Ku J, *et al*. Analysis of cost outliers after gastric bypass surgery: what can we learn? *Obes Surg* 2003; **13**: 29–36.
17. Dallal RM, Mattar SG, Lord JL, *et al*. Results of laparoscopic gastric bypass in patients with cirrhosis. *Obes Surg* 2004; **14**: 47–53.
18. Gandhi GY, Nuttall GA, Abel MD, *et al*. Intraoperative hyperglycemia and perioperative outcomes in cardiac surgery patients. *Mayo Clin Proc* 2005; **80**: 862–6.
19. Serafini FM, MacDowell Anderson W, Rosemurgy AS, Strait T, Murr MM. Clinical predictors of sleep apnea in

patients undergoing bariatric surgery. *Obes Surg* 2001; **11**: 28–31.

20. Villegas L, Schneider B, Provost D, *et al*. Is routine cholecystectomy required during laparoscopic gastric bypass? *Obes Surg* 2004; **14**: 206–11.
21. Kral JG, Thung SN, Biron S, *et al*. Effects of surgical treatment of the metabolic syndrome on liver fibrosis and cirrhosis. *Surgery* 2004; **135**: 48–58.
22. Siegelman ES, Rosen MA. Imaging of hepatic steatosis. *Semin Liver Dis* 2001; **21**: 71–80.
23. Stratopoulos C, Papakonstantinou A, Terzis I, *et al*. Changes in liver histology accompanying massive weight loss after gastroplasty for morbid obesity. *Obes Surg* 2005; **15**: 1154–60.
24. Barker KB, Palekar NA, Bowers SP, Goldberg JE, Pulcini JP, Harrison SA. Non-alcoholic steatohepatitis: effect of Roux-en-Y gastric bypass surgery. *Am J Gastroenterol* 2006; **101**: 368–73.
25. Lieske JC, Kumar R, Collazo-Clavell ML. Nephrolithiasis after bariatric surgery for obesity. *Sem Nephrol* 2008; **28**: 163–73.
26. Sinha MK, Collazo-Clavell ML, Rule A, *et al*. Hyperoxaluric nephrolithiasis is a complication of Roux-en-Y gastric bypass surgery. *Kidney Int* 2007; **72**: 100–7.
27. Service GJ, Thompson GB, Service FJ, Andrews JC, Collazo-Clavell ML, Lloyd RV. Hyperinsulinemic hypoglycemia with nesidioblastosis after gastric-bypass surgery. *N Engl J Med* 2005; **353**: 249–54.
28. Helfand M, Redfern CC. Clinical guideline, part 2. Screening for thyroid disease: an update. American College of Physicians. *Ann Intern Med* 1998; **129**: 144–58.
29. McGlinch BP, Que FG, Nelson JL, Wrobleski DM, Grant JE, Collazo-Clavell ML. Perioperative care of patients undergoing bariatric surgery. *Mayo Clin Proc* 2006; **81**(10 Suppl): S25–33.
30. Fabricatore AN, Crerand CE, Wadden TA, Sarwer DB, Krasucki JL. How do mental health professionals evaluate candidates for bariatric surgery? Survey results. *Obes Surg* 2006; **16**: 567–73.
31. Walfish S, Vance D, Fabricatore AN. Psychological evaluation of bariatric surgery applicants: procedures and reasons for delay or denial of surgery. *Obes Surg* 2007; **17**: 1578–83.
32. Rosik CH. Psychiatric symptoms among prospective bariatric surgery patients: rates of prevalence and their relation to social desirability, pursuit of surgery, and follow-up attendance. *Obes Surg* 2005; **15**: 677–83.
33. Grilo CM, White MA, Masheb RM, Rothschild BS, Burke-Martindale CH. Relation of childhood sexual abuse and other forms of maltreatment to 12-month postoperative outcomes in extremely obese gastric bypass patients. *Obes Surg* 2006; **16**: 454–60.
34. Bauchowitz AU, Gonder-Frederick LA, Olbrisch M-E, *et al*. Psychosocial evaluation of bariatric surgery candidates: a survey of present practices. *Psychosomatic Med* 2005; **67**: 825–32.
35. Galvani C, Gorodner M, Moser F, *et al*. Laparoscopic adjustable gastric band versus laparoscopic Roux-en-Y gastric bypass: ends justify the means? *Surg Endoscopy* 2006; **20**: 934–41.
36. Jan JC, Hong D, Bardaro SJ, July LV, Patterson EJ. Comparative study between laparoscopic adjustable gastric banding and laparoscopic gastric bypass: single-institution, 5-year experience in bariatric surgery[erratum appears in *Surg Obes Relat Dis* 2007; **3**: 203]. *Surg Obes Relat Dis* 2007; **3**: 42–50; discussions 1.
37. Hsu LK, Benotti PN, Dwyer J, *et al*. Nonsurgical factors that influence the outcome of bariatric surgery: a review. *Psychosom Med* 1998; **60**: 338–46.
38. Campos GM, Rabl C, Mulligan K, *et al*. Factors associated with weight loss after gastric bypass. *Arch Surg* 2008; **143**: 877–83; discussion 84.
39. Melton GB, Steele KE, Schweitzer MA, Lidor AO, Magnuson TH. Suboptimal weight loss after gastric bypass surgery: correlation of demographics, comorbidities, and insurance status with outcomes. *J Gastrointest Surg* 2008; **12**: 250–5.
40. Alvarado R, Alami RS, Hsu G, *et al*. The impact of preoperative weight loss in patients undergoing laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2005; **15**: 1282–6.
41. Jamal MK, DeMaria EJ, Johnson JM, *et al*. Insurance-mandated preoperative dietary counseling does not improve outcome and increases dropout rates in patients considering gastric bypass surgery for morbid obesity. *Surg Obes Relat Dis* 2006; **2**: 122–7.
42. Harnisch MC, Portenier DD, Pryor AD, Prince-Petersen R, Grant JP, DeMaria EJ. Preoperative weight gain does not predict failure of weight loss or co-morbidity resolution of laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Surg Obes Relat Dis* 2008; **4**: 445–50.
43. Silecchia G, Bacci V, Bacci S, *et al*. Reoperation after laparoscopic adjustable gastric banding: analysis of a cohort of 500 patients with long-term follow-up. *Surg Obes Relat Dis* 2008; **4**: 430–6.
44. Wolnerhanssen BK, Peters T, Kern B, *et al*. Predictors of outcome in treatment of morbid obesity by laparoscopic adjustable gastric banding: results of a prospective study of 380 patients. *Surg Obes Relat Dis* 2008; **4**: 500–6.
45. Wadden TA, Berkowitz RI, Womble LG, *et al*. Randomized trial of lifestyle modification and pharmacotherapy for obesity. *N Engl J Med* 2005; **353**: 2111–20.

46. Wadden TA, Foster GD, Letizia KA. One-year behavioral treatment of obesity: comparison of moderate and severe caloric restriction and the effects of weight maintenance therapy. *J Consult Clin Psychol* 1994; **62**: 165–71.

47. Gibbons RJ, Balady GJ, Bricker JT, *et al*. ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). *Circulation* 2002; **106**: 1883–92.

Section 3
Chapter 9

Intra-operative management

Positioning

Jay B. Brodsky

9.1 Introduction

An improperly positioned surgical patient can experience serious physiologic impairment and even physical injury. Intra-operative positioning considerations are even more important for the obese patient. Obesity is normally associated with significant physiologic changes, and each surgical position can further alter already compromised base-line cardiopulmonary function. Obese patients are also more likely to experience neurologic injuries or other serious complications if placed in a non-physiologic position. Alternately, proper positioning can facilitate important aspects of anesthetic care including airway management, oxygenation, and tracheal intubation.

9.2 General considerations

Problems associated with obesity are not only limited to medical comorbidities. Severely overweight people may be too large for standard equipment such as wheelchairs, waiting-room armchairs, MRI and CAT scanners, angiogram tables, and hospital beds. Standard operating room gurneys and beds are often too small or too uncomfortable for the very obese patient.

Sufficient manpower must also be available before attempting to move a MO patient. Transfer to the operating room table or turning the patient from the supine to the prone or lateral positions requires the coordinated help of many people.

Healthcare workers consistently rank among top occupations with disabling back injuries, primarily from lifting patients. Back injury may be the single largest contributor to our current nursing shortage. Use of mechanical patient lift equipment prevents back injury. Several states are considering or have passed legislation to require a "Safe Patient Handling – No Manual Lift" policy that would require a mechanical lifting device be used for obese patients [1].

One useful transfer device is the Airpal® (Patient Transfer Systems, Central Valley, PA, USA) system [2]. A reusable nylon pad, similar to a bed sheet, is placed under the patient. A lightweight portable air supply is attached and used to inflate the pad. The air "lifts" the patient as it is released through the perforated underside of the pad, and the patient is transferred on a cushioned film of air. Just two staff members can move a MO patient with minimal physical exertion.

New operating tables are designed to hold larger patients. A document sponsored by the American College of Surgeons states that "the operating room environment required for performance of bariatric surgery [should] have special operating room tables and ancillary equipment available to accommodate patients weighing up to 750 lbs" [3]. The number of these special tables available in any operating suite is limited. If a conventional older table has to be used it must be remembered that they are not designed for extremely large patients and may need additional support for a very heavy load. If a single table is not wide enough, two standard tables can be placed side-to-side to accommodate a very large patient.

9.3 Supine position

The pathophysiology of obesity is reviewed in detail elsewhere in this book. Briefly, awake, spontaneously breathing obese patients demonstrate decreased chest wall compliance and inefficient respiratory muscles. Work of breathing increases with increasing obesity, and is associated with increased oxygen consumption and carbon dioxide production [4]. With increasing weight, intra-abdominal pressure increases and expiratory reserve volume (ERV), a component of functional residual capacity (FRC), decreases [5]. During normal tidal ventilation airway closure leads to air trapping, shunting, and a PaO_2 lower than would be expected in a

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similar normal weight patient With obesity cardiac output, systemic and pulmonary artery pressures, and left and right ventricular pressures increase with age [6].

For any patient simply changing from standing or sitting to the supine position causes an increase in venous blood return to the heart. Cardiac output, pulmonary blood flow, and arterial blood pressure all increase in the supine position. Abdominal contents limit diaphragmatic movement in turn reducing FRC. In normal or slightly overweight patients (BMI < 29 kg m^{-2}) there are significant declines in pulmonary function after changing from sitting to supine [7]. General anesthesia with muscle paralysis further reduces lung volumes. These cardio-respiratory changes are exaggerated in obesity [8,9].

Spontaneously breathing extremely obese patients should never be allowed to lie completely flat. In the operating room prior to anesthetic induction, their upper body should be elevated 30°–45° in the semi-recumbent (semi-Fowler's) position with the entire operating room table tilted in the reverse Trendelenburg position to allow adequate ventilation.

The supine position causes a marked increase in intra-abdominal pressure, which results in a splinting effect of abdominal contents on the diaphragm [10]. Supine obese patients have relative hypoxemia and significant alterations in the mechanical properties of their respiratory system with marked reductions in lung volume [11]. In the spontaneously breathing obese patient, the increased diaphragmatic load causes a marked reduction in expiratory flow and an increase in intrinsic positive end-expiratory pressure (PEEP) [12]. The supine MO patient experiences a proportionally greater decrease in FRC, total respiratory system, and pulmonary compliance, and a larger ventilation/perfusion (V/Q) mismatch than a normal weight patient, and all changes increase with increasing BMI [10].

Relieving or reducing intra-abdominal pressure increases FRC and improves oxygenation [13]. This was dramatically demonstrated in a supine 350 kg patient. Mechanically lifting her massive panniculus during surgery, without any other changes in ventilatory parameters, relieved intra-abdominal pressure and resulted in a marked increase in PaO_2 [14]. Simply opening the abdomen of an obese patient leads to an increase in pulmonary compliance, and lung volumes return towards normal values [15].

Changing from the sitting to supine position causes significant increases in oxygen consumption, cardiac output, and pulmonary artery pressure in obese patients. By lying down, a decrease in already poor chest wall compliance, further V/Q mismatch, and a sudden shift of blood to an already hyperactive, borderline hypoxic heart can occur. In patients with inadequate cardiac reserve these changes can lead to fatal cardio-respiratory decompensation, termed "obesity supine death syndrome" [16].

Compression of the inferior vena cava in the supine position reduces venous return to the heart. This can be avoided by tilting the operating room table or by placing a wedge under the patient, maneuvers similar to those performed during cesarean section to reduce the pressure of the gravid uterus on the inferior vena cava.

9.4 Head-up positions

Awake, spontaneously breathing obese patients should be in a head-up (semi-recumbent, reverse Trendelenburg) position. A head-up position unloads the weight of the intra-abdominal contents from the diaphragm. MO patients in the reverse Trendelenburg position demonstrate increased pulmonary compliance and FRC and oxygenation compared to when they are supine [17].

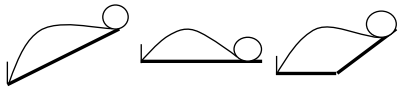
Prior to induction of general anesthesia obese patients should be positioned with their head and upper body elevated in such a way that an imaginary horizontal line can be drawn from the patient's sternum to their ear (Figure 9.1). This "stacked", "ramped", or "head-elevated laryngoscopy position" (HELP) improves pulmonary compliance, allows easier mask ventilation, and improves conditions for tracheal intubation [18]. Improved laryngeal exposure increases the rate of successful tracheal intubation [19, 20].

The HELP position can be obtained by placing towels, blankets, and/or pillows under the patient's back and shoulders. Commercial devices such as sponge elevation pillows [21] and even 3-l irrigation bags can be used to achieve the HELP position [22]. Once the patient's trachea is successfully intubated, repositioning to a supine or lithotomy position may be necessary. An inflatable device is available which allows initial positioning in a head-up position, deflation during surgery, and then reinflation for tracheal extubation [23].

Hypoxemia during induction of general anesthesia in the MO patient is always a concern.

Anesthetic induction is usually performed with the patient supine. If this is done in an obese patient, the combined effects of reduced FRC and increased metabolic rate result in rapid oxyhemoglobin desaturation.

Figure 9.1 The head-elevated laryngoscopy position (HELP) is achieved by positioning the patient's head and upper body in such a way that an imaginary horizontal line can be drawn from the patient's sternum to their ear. The HELP position combined with the operating table in reverse Trendelenburg increases safe apnea time (time in seconds that oxyhemoglobin saturation remains > 92% during apnea) allowing more time for tracheal intubation and to improve the view during direct laryngoscopy.



Safe apnea period (seconds)	178±55 (1 vs 3:p<0.05)	123±24	153±63
Recovery time (seconds)	80±30 (2 vs 1:*P*<0.001)	206±64	97±41 (2 vs 3:*P*<0.001)
Lowest SaO_2(%)	83±4	82±5	83±4

Data is mean±Standard deviation.

Figure 9.2 In obese patients safe apnea time was longest in the reverse Trendelenburg position and shortest in the supine position. Following adequate preoxygenation and paralysis, the reverse Trendelenburg position allows extra time to secure the airway before oxyhemoglobin desaturation can occur. From: Ref [25].

MO patients were pre-oxygenated in either the supine or sitting position prior to undergoing a rapid sequence induction of anesthesia with thiopental and succinylcholine. Once paralyzed, the patients were placed supine. Following successful tracheal intubation the patients were left apneic until SaO_2 decreased to 90%. The time to arterial desaturation ("safe apnea time") was significantly longer (214 sec +/− 28) in the sitting group compared to the supine group (162 sec +/− 38) [24]. Patients randomized to a 30° reverse Trendelenburg position experienced longer safe apnea periods (178 sec +/− 55) than those in either the 30° semi-Fowler's (153 sec +/− 63) or supine positions (123 sec +/− 24) [25] (Figure 9.2).

Proper positioning is essential. Pre-oxygenation in a head-up position results in increased arterial oxygenation and longer time before hemoglobin desaturation occurs [26]. Since the reverse Trendelenburg position allows extra time to secure the airway before desaturation, and the HELP position improves view during laryngoscopy, our practice is to combine both for induction of anesthesia in our MO patients.

The efficacy of PEEP or the reverse Trendelenburg position were compared in MO patients undergoing laparoscopic bariatric procedures [27]. Both PEEP and the reverse Trendelenburg position improved oxygenation, and total respiratory compliance. There were no significant differences with regard to gas exchange, but both PEEP and the reverse Trendelenburg position were associated with a drop in cardiac output. Any beneficial effects on oxygenation could, in theory, be offset if cardiac output decreased significantly.

If the obese patient is hemodynamically stable at the completion of surgery, the trachea should be extubated with their upper body elevated 30°–45°. Patients should then be transferred from the operating room in a semi-recumbent or tilted reverse Trendelenburg position.

Following abdominal surgery obese patients have a greater reduction in lung volumes compared to normal weight patients [28]. Patients should recover from anesthesia in a head-up position to minimize intrapulmonary shunting [29]. Since change from the semi-recumbent to the supine position results in a significant decrease in PaO_2, obese patients should always convalesce in the semi-recumbent position while receiving supplemental oxygen [30].

9.5 Head-down (Trendelenburg) position

In the Trendelenburg position the patient's head is below the horizontal plane. This position is used during selected surgical procedures to improve operative exposure and reduce bleeding. The Trendelenburg position can also be used to engorge neck veins to facilitate central venous cannulation.

Spontaneously breathing obese patients generally do not tolerate the Trendelenburg position. In the Trendelenburg position there is an auto-transfusion of blood from the lower extremities into the central and pulmonary circulation. The added weight of the abdominal contents pressing on the diaphragm plus the weight of the chest wall further decrease total compliance and FRC, which in turn leads to increased atelectasis and hypoxemia.

Arterial blood gas samples were obtained from MO patients undergoing jejunoileal bypass procedures placed in the supine and then in a 15° head-down (Trendelenburg) position [31]. Although ventilation with FiO_2 0.4 did not uniformly produce adequate arterial oxygenation in either position, a change from supine to Trendelenburg resulted in additional decreases in PaO_2. The combination of Trendelenburg position with placement of sub-diaphragmatic packs, which further impeded diaphragmatic excursion, was particularly dangerous.

For any size patient, changing from the supine to the Trendelenburg position can result in advancement of the tip of the endotracheal tube deeper into the airway. The potential for tube misplacement is greater in MO patients, especially during laparoscopy. If it results in bronchial intubation, there will be a further decrease in pulmonary compliance and oxygenation.

The Trendelenburg position should be avoided if possible in a MO patient. If an anesthetized obese patient must be placed head-down, their trachea should be intubated and ventilation should be mechanically controlled.

9.6 Prone position

For an anesthetized and paralyzed normal weight patient, placement in the prone position improves oxygenation compared to the same patient when supine [32]. If the abdominal wall is allowed to hang freely, there is a reduction in cephalad displacement of the diaphragm and a reopening of atelectactic lung segments. However, if the abdomen is compressed and not free to move, diaphragmatic movement will be impeded and chest wall movement restricted.

In mild to moderately obese patients, respiratory mechanics, lung volumes, and oxygenation all increase when changing from the supine to prone position. Less airway pressure is required to ventilate the lungs of prone MO patients compared to when those same patients were supine. In a study of paralyzed, anesthetized obese patients (BMI > 30 kg m^{-2}), measurements of respiratory function were made in the supine and prone positions. The same ventilatory settings and FiO_2 (0.4) were maintained in both positions. There was an increase in FRC and lung compliance, and a significant increase in PaO_2 when the patients were changed from supine to prone [33].

Therefore, the prone position is usually well tolerated by obese patients as long as the upper chest and pelvis are adequately supported to ensure free abdominal movement. The unloading of abdominal viscera significantly reduces pressure on the diaphragm, which in turn leads to an increase in FRC. For very large patients the thorax and pelvis may have to be raised as high as 2 ft (60 cm) above the operating table. This can be accomplished using large pelvic and chest supports [34].

When properly positioned, cardiovascular function is maintained in prone normal weight patients [35]. The abdominal viscera must be free in order to reduce pressure on the inferior vena cava. If the inferior vena cava or femoral veins are compressed then venous return to the heart will decrease resulting in decreased left ventricular filling and hypotension [36]. In an improperly positioned prone patient blood pressure may be further decreased from the increased intra-thoracic pressures generated during mechanical ventilation [37].

9.7 Lateral decubitus position

Because of the difficulties moving and positioning MO patients, procedures routinely performed prone are often done in the lateral decubitus position [38]. There are few clinical reports as to how obese patients tolerate the lateral position.

In normal weight patients changing from supine to the lateral decubitus position is not associated with any significant hemodynamic effects. If a kidney rest is used, cardiac output can be reduced due to a decrease in venous return and an increase in systemic vascular resistance.

In an experimental study of five MO volunteers, changing from the seated position to the lateral decubitus position resulted in a reduction in dependent lung volume. The mechanism for this change, whether due to position alone or mechanical dysfunction of the diaphragm or intercostal muscles in these spontaneously breathing patients, was not determined [39].

Our clinical experience has been that MO surgical patients tolerate the lateral position. Oxygenation with one-lung ventilation in MO patients undergoing thoracotomy in the lateral decubitus position was satisfactory in all patients [40]. We postulated that their ability to successfully undergo one-lung ventilation may have been due to displacement of their panniculus off the abdomen, which in turn reduced intra-abdominal pressure and allowed greater diaphragmatic excursion during mechanical ventilation.

In order to avoid the problems of the supine position, induction of general anesthesia in the lateral decubitus position has been recommended for MO

patients [41]. With the patient in the HELP position this approach seems unnecessary and impractical.

9.8 Lithotomy position

In the lithotomy position the patient is on their back with their legs and thighs flexed at right angles. The patient may also be head-down. In this position vital capacity decreases in normal patients breathing spontaneously due to restriction of diaphragmatic movement. Venous return to the heart is increased causing an increase in cardiac output and increased pulmonary blood flow. MO patients placed in lithotomy experience increased intra-abdominal pressure and compression of the lungs, which can further reduce chest wall compliance.

For MO patients undergoing procedures in the lithotomy position, positive-pressure ventilation with an endotracheal tube is recommended to compensate for the decreased lung volume.

9.9 Complications of positioning

Potential pressure points must always be adequately padded before the induction of anesthesia. The risk of pressure sores, neural injuries, and rhabdomyolysis (RML) from prolonged stasis during surgery is higher in an obese than in a normal weight patient. For diabetic obese patients these risks are further increased. Normal amounts of padding may be insufficient to prevent the increased weight of the adipose tissue from injuring nerves and vascular structures [42]. The patient's arms must be carefully supported to avoid stretch or compression that can lead to brachial plexus injury.

MO patients are at special risk for RML, a potentially fatal post-operative complication. Muscle injury results from unrelieved pressure injury to the lower limbs, and gluteal and lumbar muscles during prolonged procedures in a non-physiologic position. The majority of RML cases in obese patients have followed surgery in the supine or lithotomy positions, probably because bariatric procedures are performed in those positions. However, RML can occur with any operative position. Prevention begins with careful intra-operative padding of all pressure points and close attention to patient positioning. Some clinicians even suggest changing patient position hourly during long operations. Minimizing operative time, adequate peri-operative hydration, and close post-operative monitoring are important [43].

Combining the reverse Trendelenburg position and pneumoperitoneum during laparoscopic gastric bypass surgery may reduce femoral blood flow and increases venous stasis, increasing the risk of pulmonary embolism [44]. The use of sequential compression devices is only partially effective in reversing the reduction in femoral peak systolic velocity.

Prolonged surgery in the prone position in a poorly positioned patient can cause serious complications. If the abdomen is compressed impairing vena caval flow, collateral venous drainage will engorge the vertebral and epidural veins. This coupled with arterial hypotension can compromise spinal cord perfusion and has produced spinal cord ischemia [45]. At least one case of ischemic optic neuropathy from venous engorgement was reported in an prone obese, diabetic patient [46].

MO patients have elevated vitreous pressure, leading to a high rate of complications following cataract surgery. Cataract surgery performed with the MO patient in the reverse Trendelenburg position can reduce the risk of posterior capsule rupture and vitreous loss [47].

Depending on the method of leg support used, the lithotomy position can cause changes in intra-compartment pressure in the calf or knee. Compartment syndrome, a condition in which increased tissue pressure within a limited tissue space compromises circulation and function of the contents in that space, is a potential complication of the lithotomy position. The longer the patient is in lithotomy, the greater the chances of developing lower extremity neuropathy or compartment syndrome. Because of the heavier weight of their lower extremities, obese patients are at special risk [48]. The use of intermittent external compression devices can reduce intra-compartment pressure. The obese patient in the lithotomy position is also at a greater risk from transient neurologic symptoms, particularly following spinal anesthesia [49].

The combination of obesity and the lithotomy position may also increase the risk of gastric reflux and pulmonary aspiration [50]. Venous stasis with thrombo-embolism is common with the lithotomy position, and obesity increases the risk of this complication as well [51].

9.10 Conclusions

The intra-operative management of a MO surgical patient can be a challenge. Familiarity with the pathophysiology of obesity combined with knowledge of how intra-operative positioning can further impact cardio-pulmonary function reduces many of the risks.

References

1. Edlich RF, Hudson MA, Buschbacher RM, *et al*. Devastating injuries in healthcare workers: description of the crisis and legislative solution to the epidemic of back injury from patient lifting. *J Long Term Eff Med Implants* 2005; **15**: 225–41.
2. Kartha V, Gomez W, Bullough A. Transfer device for supermorbidly obese patients. *Anaesthesia* 2008; **63**: 102.
3. Recommendations for facilities performing bariatric surgery. *Bull Am Coll Surg* 2000; **85**; No. 9.
4. Luce JM. Respiratory complications of obesity. *Chest* 1980; **78**: 626–31.
5. Biring MS, Lewis MI, Liu JI, *et al*. Pulmonary physiologic changes of morbid obesity. *Am J Med Soc* 1999; **318**: 293–7.
6. Alexander JK. Obesity and cardiac performance. *Am J Cardiology* 1964: **14**; 860–5.
7. Vilke GM, Chan TC, Neuman T, *et al*. Spirometry in normal subjects in sitting, prone, and supine positions. *Respir Care* 2000; **45**: 407–10.
8. Paul DR, Hoyt JL, Boutrous AR. Cardiovascular and respiratory changes in response to change in posture in the very obese. *Anesthesiology* 1976; **45**: 73–7.
9. Yap JC, Watson RA, Gilbey S, *et al*. Effects of posture on respiratory mechanics in obesity. *J Appl Physiol* 1995; **79**: 1199–205.
10. Pelosi P, Croci M, Ravagnan I, *et al*. Respiratory system mechanics in sedated, paralyzed, morbidly obese patients. *J Appl Physiol* 1997; **82**: 811–8.
11. Ferretti A, Giampiccolo P, Cavalli A, *et al*. Expiratory flow limitation and orthopnea in massively obese subjects. *Chest* 2001; **119**: 1401–8.
12. Pankow W, Podszus T, Gutheil T, *et al*. Expiratory flow limitation and intrinsic positive end-expiratory pressure in obesity. *J Appl Physiol* 1998; **85**: 1236–43.
13. Tsueda K, Pugh ST, Boyan P. Pattern of oxygenation during intestinal bypass for morbid obesity. *Anesthesiology* 1976; **45**: 668–70.
14. Wyner J, Brodsky JB, Merrell RC. Massive obesity and arterial oxygenation. *Anesth Analg* 1981; **60**: 691–3.
15. Aueler JO Jr, Miyoshi E, Fernandes CR, *et al*. The effects of abdominal opening on respiratory mechanics during general anesthesia in normal and morbidly obese patients: a comparative study. *Anesth Analg* 2002; **94**: 741–8.
16. Tsueda K, Debrand M, Zeok SS, *et al*. Obesity supine death syndrome: reports of two morbidly obese patients. *Anesth Analg* 1979; **58**: 345–7.
17. Perilli V, Sollazzi L, Bozza P, *et al*. The effects of the reverse Trendelenburg position on respiratory mechanics and blood gases in morbidly obese patients during bariatric surgery. *Anesth Analg* 2000; **91**: 1520–5.
18. Brodsky JB, Lemmens HJM, Brock-Utne JG, *et al*. Morbid obesity and tracheal intubation. *Anesth Analg* 2002; **94**: 732–6.
19. Collins JS, Lemmens HJ, Brodsky JB, *et al*. Laryngoscopy and morbid obesity: a comparison of the "sniff" and "ramped" positions. *Obes Surg* 2004; **14**: 1171–5.
20. Brodsky JB, Lemmens HJ, Brock-Utne JG, *et al*. Anesthetic considerations for bariatric surgery: proper positioning is important for laryngoscopy. *Anesth Analg* 2003; **96**: 1841–2.
21. Rich JM. Use of an elevation pillow to produce the head-elevated laryngoscopy position for airway management in morbidly obese and large-framed patients. *Anesth Analg* 2004; **98**: 264–5.
22. Wong AB, Moore MSR. Positioning of obese patients in out-of-operating room locations. *Anesth Analg* 2007; **104**: 1306.
23. Nissen MD, Gayes JM. An inflatable, multichambered upper body support for the placement of the obese patient in the head-elevated laryngoscopy position. *Anesth Analg* 2007; **104**: 1305–6.
24. Altermatt FR, Munoz HR, Delfino AE, *et al*. Pre-oxygenation in the obese patient: effects of position on tolerance to apnoea. *Brit J Anaesth* 2005: **95**: 706–9.
25. Boyce JR, Ness T, Castroman P, *et al*. A preliminary study of the optimal anesthesia positioning for the morbidly obese patient. *Obes Surg* 2003; **13**: 4–9.
26. Dixon BJ, Dixon JB, Carden JR, *et al*. Preoxygenation is more effective in the 25° head-up position than in the supine position in severely obese patients. *Anesthesiology* 2005; **102**: 1110–5.
27. Perilli V, Sollazzi L, Modesti C, *et al*. Comparison of positive end-expiratory pressure with reverse Trendelenburg position in morbidly obese patients undergoing bariatric surgery: effects on hemodynamics and pulmonary gas exchange. *Obes Surg* 2003; **13**: 605–9.
28. Pelosi P, Croci M, Ravagnan I, *et al*. Total respiratory system, lung, and chest wall mechanics in sedated-paralyzed postoperative morbidly obese patients. *Chest* 1996; **109**: 144–51.
29. Vaughan RW, Bauer S, Wise L. Effect of position (semirecumbent versus supine) on postoperative oxygenation in markedly obese subjects. *Anesth Analg* 1976; **55**: 37–41.
30. Vaughan RW, Wise L. Postoperative arterial blood gas measurements in obese patients: effect of position on gas exchange. *Ann Surg* 1975; **182**: 705–9.
31. Vaughan RW, Wise L. Intraoperative arterial oxygenation in obese patients. *Ann Surg* 1976; **184**: 35–42.
32. Pelosi P, Croci M, Calappi E, *et al*. The prone position during general anesthesia minimally affects respiratory

mechanics while improving functional residual capacity and increasing oxygen tension. *Anesth Analg* 1995; **80**: 955–60.

33. Pelosi P, Croci M, Calappi E, *et al*. Prone positioning improves pulmonary function in obese patients during general anesthesia. *Anesth Analg* 1996; **83**: 578–83.
34. Brodsky JB, Oldroyd M, Winfield HN, et al. Morbid obesity and the prone position: A case report. *J Clin Anesth* 2001; **13**: 138–40.
35. Wadsworth R, Anderton JM, Wohra A. The effect of four different surgical prone positions on cardiovascular parameters in healthy volunteers. *Anaesthesia* 1996; **51**: 819–22.
36. Lee TC, Yang LC, Chen HJ. Effect of patient position and hypotensive anesthesia on inferior vena caval pressure. *Spine* 1998; **23**: 941–7.
37. Toyota S, Amaki Y. Hemodynamic evaluation of the prone position by transesophageal echocardiography. *J Clin Anesth* 1998; **10**: 32–5.
38. Gofrit ON, Shapiro A, Donchin Y, *et al*. Lateral decubitus position for percutaneous nephrolithotripsy in the morbidly obese or kyphotic patient. *J Endourol* 2002; **16**: 383–6.
39. Hurewitz AN, Susskind H, Harold WH. Obesity alters regional ventilation in lateral decubitus position. *J Appl Physiol* 1985; **59**: 774–83.
40. Brodsky JB, Wyner J, Ehrenwerth, *et al*. One-lung anesthesia in morbidly obese patients. *Anesthesiology* 1982; **57**: 132–4.
41. Aono J, Ueda K, Ueda W, *et al*. Induction of anaesthesia in the lateral decubitus position in morbidly obese patients. *Br J Anaesth* 1999; **83**: 356.
42. Schulz-Stubner S. Bilateral occipital neuropathy as a rare complication of positioning for thyroid surgery in a morbidly obese patient. *Acta Anaesthesiol Scand* 2004; **48**: 126–7.
43. de Menezes Ettinger JE, dos Santos Melo CA, *et al*. Prevention of rhabdomyolysis in bariatric surgery. *Obes Surg* 2005; **15**: 874–9.
44. Nguyen NT, Cronan M, Braley S, *et al*. Duplex ultrasound assessment of femoral venous flow during laparoscopic and open gastric bypass. *Surg Endosc* 2003; **17**: 285–90.
45. Bhardwaj A, Long DM, Ducker TB, *et al*. Neurologic deficits after cervical laminectomy in the prone position. *J Neurosurg Anesthesiol* 2001; **12**: 314–9.
46. Dilger JA, Tetzlaff JE, Bell GR, *et al*. Ischaemic optic neuropathy after spinal fusion. *Can J Anaesth* 1998; **45**: 63–6.
47. Mansour AM, Al-Dairy M. Modifications in cataract surgery for the morbidly obese patient. *J Cataract Refract Surg* 2004; **30**: 2265–8.
48. Gorecki PJ, Cottam D, Ger R, *et al*. Lower extremity compartment syndrome following a laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2002; **12**: 289–91.
49. Freedman JM, Li DK, Drasner K, *et al*. Transient neurologic symptoms after spinal anesthesia: an epidemiologic study of 1,863 patients. *Anesthesiology* 1998; **89**: 633–41.
50. Smith G, Ng A. Gastric reflux and pulmonary aspiration in anaesthesia. *Minerva Anesthesiol* 2003; **69**: 402–6.
51. Adachi T, Nakabayashi M, Takeda Y. Management of venous thrombosis and pulmonary embolism after gynecological surgery. *Semin Thromb Hemost* 1998; **24**: 437–42.

Chapter 10

Monitoring the morbidly obese patient

Donald P. Bernstein

10.1 Introduction

In anesthesia practice we monitor patients to determine if measured or calculated physiologic variables are within a normal range. If they are not, we are obligated to decide whether therapy is necessary. In many cases, variables such as heart rate and blood pressure (BP) are outside the range of normal, but may still be appropriate. Thus, to monitor effectively, treatments for a given deviation from the physiologic norm require proper interpretation of the clinical situation. Successful monitoring is a multitasking endeavor, sometimes requiring coherent integration of multiple unrelated variables to make a single therapeutic decision. When these variables are therapeutically optimized to desired predetermined values, we call this "goal-directed" therapy. This chapter concerns itself with peri-operative monitoring of the heart, circulation, respiratory system and brain function in the MO surgical patient.

10.2 Blood pressure measurement

Intra-arterial BP monitoring is the gold standard, but is not necessarily applicable or necessary in the otherwise "healthy" MO patient undergoing a simple surgical procedure. In these instances, automated oscillometric methods giving intermittent data are sufficient. However, as compared to correctly calibrated intra-arterial BP measurements, automated oscillometry underestimates BP at all levels, especially systolic blood pressure (SBP) [1]. These deficiencies can be partially overcome by use of smaller cuff sizes. Since rectangular BP cuffs are designed to be used on a "cylindrical" brachium, they often do not fit the upper arm of MO patients whose upper arms are sometimes conical in configuration. For this reason, blood pressure cuffs are frequently placed on the lower arm or leg. Lower arm measurements overestimate BP.

Applanation tonometry is another non-invasive technique that transduces BP from the radial artery at the wrist. Measurements are displayed continuously with short averaging periods and frequent updates. After application of a restrictive cuff, these devices partially flatten (i.e., applanate) or occlude the radial artery, and through algorithmic autocalibration, determine the SBP, diastolic blood pressure (DBP) and mean arterial blood pressure (MAP). As relates to at least one commercially available device, and as compared to intra-arterial BP measurements, BPs obtained by applanation tonometry are interchangeable [2]. To master the technique requires a learning curve related to the set-up routine and skill in properly placing the pressure transducer over the radial artery. The technique is useful in situations where continuous real-time BP is desirable and represents a non-invasive alternative to radial artery cannulation, especially when blood gas analysis is not required.

In patients who are to undergo complicated or temporally protracted surgical procedures, or those whose physical status warrants continuous BP, it cannot be overemphasized that properly transduced intra-arterial BP is without peer. Despite its invasiveness, complications are rare.

10.3 Central venous pressure and pulmonary artery occluded pressure

Central venous pressure (CVP) is a frequently monitored variable but has little diagnostic significance. It was erroneously believed at one time that changes in CVP reflected both response to fluid loading and the adequacy of circulating blood volume. Factors affecting CVP include a plethora of independent variables that may increase in the same direction, move in opposite directions or a combination of the two. Factors that decrease CVP include venodilation of the great venous

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capacitance system (relative hypovolemia) and absolute hypovolemia. The main factors which increase CVP include a decrease in cardiac pump function, a shift from unstressed blood volume (the volume of blood not generating pressure in the vessels) to stressed blood volume (the volume of blood generating pressure in the vessels), an increase in stressed blood volume and an increase in intra-thoracic pressure and/or pericardial pressure. Other factors increasing CVP include increased pulmonary arterial resistance due to hypoxic pulmonary vasoconstriction. Thus, it is the dynamic interaction of these variables which determine the magnitude of CVP, and as such, its value represents an intensity-weighted mean not necessarily reflecting blood volume or cardiac pump function. A correlation between CVP and blood volume, per se, has never been found, because it does not exist [3]. A comprehensive review of the literature convincingly indicates that there is a very poor, if not absent, relationship between CVP and blood volume, and little correlation between the change in CVP to predict the hemodynamic response to a fluid challenge [4]. Central venous pressure should not be used to make clinical decisions regarding fluid management.

While the CVP itself is not a very useful measurement, the waveform describing right atrial and ventricular activity is helpful in monitoring MO patients undergoing major surgery. For a MO patient with moderate to severe pulmonary hypertension or incipient right ventricular failure, resultant tricuspid valve regurgitation can be immediately diagnosed by the abrupt appearance of large "v" waves. Thus, right ventricular dilatation and/or failure can be deduced, not from pressure measurement, but by inspection of the waveform itself.

Another useful variable that can be obtained from central venous access catheters is central venous oxygen saturation ($ScvO_2$). While generally about 5–10 mmHg higher than mixed venous oxygen saturation (SvO_2), the course of global tissue oxygen extraction can be reliably approximated. Thus, $ScvO_2$ may not be numerically equivalent to SvO_2, but it is functionally equivalent [5].

Pulmonary artery catheterization will not be discussed in this chapter, because its use has fallen into disfavor. Simply put, the pulmonary artery occluded pressure (PAOP) is not reflective of left ventricular preload or circulating blood volume. Similar to CVP, assessment of blood volume and fluid responsiveness should not be based on measurements of PAOP. While still the cornerstone for monitoring results of treatment for primary pulmonary hypertension (PPH), recent evidence shows that many MO patients simply have increased left ventricular end diastolic pressure (LVEDP), causing pulmonary venous hypertension. Basing treatment for PPH on PAOP can result in dangerous or cost-ineffective use of pulmonary vasodilators for patients with primary left ventricular dysfunction [6].

10.4 Monitoring ventricular preload responsiveness: pulse pressure variation

The degree to which fluid loading can or cannot improve stroke volume (SV) and cardiac output (CO) is important in caring for the critically-ill or injured patient. Goal-oriented intra-operative fluid administration has been shown to reduce hospital stay, critical care admissions, and mortality after surgery [7]. As discussed, and insofar as CVP and PAOP are concerned, little useful diagnostic information and therapeutic benefit is obtained from efforts designed to optimize these variables. When exaggerated, pulse pressure variation (PPV), which is the diminution of arterial pulse pressure with positive pressure lung insufflation, has been shown to predict preload responsiveness in cases where intra-thoracic blood volume is contracted [8]. Positive pressure ventilation (inspiratory phase) causes a reduction in right ventricular preload as a result of compression of the great veins entering the right heart. Right ventricular afterload is increased due to increased intra-thoracic and alveolar pressure, resulting in compression of the pulmonary arterial tree and capillaries. These perturbations of right heart preload and afterload cause reductions in left ventricular SV early in the phase when positive pressure returns to ambient pressure. For a tidal volume of 6 ml kg^{-1}, a PPV ≥13% predicts a ≥ 15% increase in CO for a 500 ml bolus. Pulse pressure variation has been shown to be much more sensitive than either CVP or PAOP in predicting responsiveness to intravenous fluids in early hemorrhagic shock [9]. Commercially available devices are being marketed which provide real-time changes in PPV, SV variation and variation of the magnitude of the pulse oximetry waveform (ΔSpO_2).

10.5 Electrocardiographic monitoring

As discussed in Chapter 1, MO patients suffer from conduction abnormalities involving bundle branch block, brady- and tachydysrhythmias, ischemic ST-T

changes, and problems with ventricular repolarization. The most common rhythm disturbance in morbid obesity, especially in patients with obstructive sleep apnea (OSA), is atrial fibrillation (AF). If sinus rhythm abruptly converts to AF during anesthesia, or in the post-operative period, acute left atrial distension due to volume overload should be suspected. For AF with rapid ventricular response, antidysrhythmic agents, electrocardioversion, and/or preload reduction should be considered.

The electrocardiographic abnormality most likely to result in sudden, unexpected cardiac death is prolonged QT interval syndrome. Since QT interval varies with heart rate, it is usually reported as corrected QT interval (QTc). When the QTc interval exceeds 440 ms, prolonged QTc is present. The QTc interval is calculated as the measured QT interval (onset of Q wave → termination of T wave) divided by the square root of the R-R interval (i.e., $QT/\sqrt{(R\text{-}R)}$). Besides the intrinsic risk in MO individuals with OSA, commonly used therapeutic medications cause increases of the QTc.

Long QT syndrome is characterized by increased risk of polymorphic ventricular tachycardia, known as *torsades de pointes.* Some drugs prolong QTc in a dose-dependent fashion; others do so at any dose. Drugs causing prolongation of the QTc do so by potassium channel blockade and include antidysrhythmics, antimicrobials, and certain psychiatric drugs including: (a) phenothiazines (thioridizine, chlorpromazine, mesoridazine); (b) butyrophenones (droperidol, haloperidol); and (c) tricyclic antidepressants [10].

In anesthesia practice, droperidol has received the most scrutiny, and its use as an antiemetic is now discouraged. It should be noted that ondansetron, another antiemetic, also increases the QTc, but, as compared to droperidol, where QTc is prolonged by 25±8 ms, ondansetron increases QTc by 17±10 ms [11]. Isoflurane, but not halothane of sevoflurane, increases the QTc, but the critical value of 440 ms is not exceeded [12].

10.6 Monitoring ventilation: arterial oxygenation and carbon dioxide elimination

Anesthesia profoundly affects respiratory function in MO patients and causes impairment of gas exchange (see Chapter 2). Functional residual capacity (FRC) is reduced by ~20% during anesthesia in normal subjects, while in the MO patient in the supine position FRC can be reduced by as much as 30–50% from normal. Consequently, more rapid and profound reductions in SaO_2 (SpO_2) with apnea on induction of anesthesia should be anticipated. As a result of the derangements in respiratory mechanics and pulmonary function, the alveolar–arterial oxygen gradient increases; this effectively reduces the PaO_2/PaO_2 ratio. Collapsing lung units and formation of atalectasis leads to alveolar ventilation/perfusion inequality (V_A/Q_T) mismatch and larger intrapulmonary shunt (Q_s/Q_t), both of which cause arterial hypoxemia. In all patients, not just MO patients, it is standard of care to monitor the fraction of inspired oxygen (FiO_2) and arterial oxygen saturation (SaO_2) by pulse oximetry (SpO_2).

In general, SpO_2 provides close approximations of SaO_2, but overestimates true SaO_2 in the presence of elevated levels of carboxyhemoglobin and provides inaccurate values with methemoglobinemia and organic dyes. SpO_2 levels should be maintained above 90% and preferably above 95% if possible. In MO individuals undergoing laparoscopy, reverse Trendelenburg position, or increasing tidal volume, and/or ventilation rate during mechanical ventilation, and administration of PEEP have been reported not to improve oxygenation [13]. Conversely, during open gastroplasty, administration of positive end-expiratory pressure and reverse Trendelenburg position both improve oxygenation, probably because of increased FRC [14].

At rest, otherwise healthy obese patients maintain normal levels of arterial carbon dioxide tension ($PaCO_2$), whereas those with chronic obstructive pulmonary disease and obesity hypoventilation syndrome have elevated levels [15]. While SpO_2 monitoring relates to the adequate transfer of inspired oxygen from the alveoli to the blood, end-tidal carbon dioxide ($P_{ET}CO_2$), without significant V_A/Q_T and Q_s/Q_t, provides evidence that the by-product of aerobic metabolism, CO_2, is being properly eliminated. In normal awake individuals, $PaCO_2$ is generally higher than $P_{ET}CO_2$ by ~ 1–5 mmHg, but, because of increased Q_s/Q_t in the morbidly obese, the disparity can be much greater.

10.7 Transcutaneous oxygen tension monitoring

Transcutaneous oxygen tension ($P_{tc}O_2$) monitoring has been used for many years in neonatal critical care as a surrogate for arterial oxygen tension (PaO_2). In adults, however, its use has never become popular.

Skin is the first organ to react to sympathetic-adrenal stress response and provides very early warning signs of impending shock, organ failure, and death [16]. Specifically, in adults who are hemodynamically stable, $P_{tc}O_2$ parallels FiO_2 and PaO_2, but in shock states, it tracks CO while contemporaneously its relationship with FiO_2 and PaO_2 deteriorates. The discrepancy between $P_{tc}O_2$ and PaO_2 is a valuable marker of early shock and inadequate peripheral tissue oxygenation [17]. The lack of subcutaneous PO_2 rise, or actual decrease in response to high levels of FiO_2, called the "oxygen challenge test" (i.e., $P_{tc}O_2/FiO_2$), is associated with higher morbidity and mortality in human subjects.

10.8 Transcutaneous carbon dioxide tension monitoring

The measurement of transcutaneous carbon dioxide tension ($P_{tc}CO_2$) represents an alternative for non-invasive estimation of $PaCO_2$. Although agreement between arterial and transcutaneous values of CO_2 in both infants and adult patients has been demonstrated, until recently, no data was available for MO adults. Recent data shows that in MO adults, agreement between $PaCO_2$ and $P_{tc}CO_2$ is satisfactory and can be used interchangeably in most situations. Unlike $P_{ET}CO_2$, which is sensitive to increased Q_s/Q_t, $P_{tc}CO_2$ is governed only by the level of arterial CO_2 and "washout" from the capillary circulation.

Transcutaneous CO_2 sensors are heated in order to induce capillary arterialization, which also increases local production of CO_2 in the tissues being interrogated. This accounts for the slightly higher $P_{tc}CO_2$ levels than $PaCO_2$ measured by arterial blood gas analysis [15]. In patients with adequate O_2 delivery and cellular oxygen utilization, $P_{tc}CO_2$ reflects the adequacy of pulmonary ventilation, but in patients with shock, inadequate capillary blood flow and reduced CO_2 evacuation, $P_{tc}CO_2$ reflects inadequate blood flow to the microcirculation of the skin. $P_{tc}CO_2$ is also valuable in the post-operative period in extubated, spontaneously breathing patients [18].

10.9 Nasal and face-mask capnometry

The ventilatory status of MO patients whose tracheas are extubated and who are breathing spontaneously in the post-anesthesia care unit (PACU)/intensive care unit (ICU) post-operatively or those receiving monitored anesthesia care (MAC) with intravenous sedation, should all be assessed using end-tidal capnometry, either by nasal cannula or mask. Regardless of the method (flow-through vs. sidestream), nasal capnometry provides $PetCO_2$ values which display little bias, but wide limits of agreement (5–10 mmHg) with respect to $PaCO_2$ [19]. As a monitor, the very presence of a CO_2 curve implies that, at the least, complete respiratory obstruction is not present. Regardless of the absolute value of $PetCO_2$, changes in the relative magnitude suggest improvement or deterioration in CO_2 production or elimination, and/or changing patency of the airway.

10.10 Temperature monitoring

Body temperature should be measured in patients undergoing general or neuraxial anesthesia procedures exceeding 30 min duration. Surgery typically involves exposure to a cold environment, unwarmed intravenous fluids, and heat loss from evaporation from surgical wounds. Hypothermia is the most common temperature abnormality and reflects a failure of effective thermoregulatory defenses [20]. All general anesthetics produce a dose-dependent reduction in core body temperature. Normal core temperatures in humans typically range from 36.5 to 37.5°C; values < 36° or > 38°C usually represent triggers for therapeutic intervention.

Hypothermia has many deleterious side-effects, including sympathetic nervous system activation, increased surgical wound infection, coagulopathy, increased transfusion requirement, negative nitrogen balance, delayed wound healing, delayed post-operative recovery, prolonged hospitalization, shivering, and patient discomfort [20, 21]. Hyperthermia can be caused by passive overheating, or much less commonly, malignant hyperthermia.

Core temperatures can be measured in the pulmonary artery, distal esophagus, tympanic membrane, or nasopharynx. Core temperatures can be reasonably estimated using oral, axillary, and bladder temperatures. For the axillary approach, the temperature probe should be ideally placed over the axillary artery with the arm to the side of the patient. Bladder temperatures are variable due to the unpredictable nature of urine flow. Forehead skin surface temperature is considerably lower than core temperature by about 2°C, but is

surprisingly accurate if the temperature differential is considered. With respect to the MO patient, intra-operative hypothermia occurs with regularity during both laparoscopic and open bariatric procedures if measures are not taken to prevent it.

10.11 Monitoring neuromuscular blockade

Succinylcholine, a depolarizing skeletal muscle relaxant, is administered on the basis of actual measured body weight (mg kg_{actual}^{-1}). Non-depolarizing neuromuscular blocking agents (NDNMBs), such as vecuronium and rocuronium, are given on the basis of ideal body weight (ml kg_{IBW}^{-1}). In the absence of a pseudocholinesterase deficiency or genetic variant, spontaneous recovery from partial or total succinylcholine paralysis occurs within minutes. On the other hand, spontaneous recovery from NDNMB is dependent on the cumulative dose of relaxant and its corresponding duration of action.

Neuromuscular activity should be monitored during surgery by train-of-four (TOF). Reversal of relaxant activity of the NDNMBs by chemical displacement (anticholinesterases) or encapsulation (sugammadex) is mandatory for all patients who demonstrate a TOF ratio of < 0.90 [22]. When patients are extubated with a TOF ratio < 0.90 the incidence of morbidity and mortality increases. Despite the patient's ability to lift his/her head from a pillow, execute a vigorous hand grip, or demonstrate adequate tidal volume while intubated, clinically relevant skeletal muscle weakness can still be present.

When NDNMBs are administered, they are reversed by an anticholinesterase, usually neostigmine. Neostigmine acts by blocking the effect of true cholinesterase. Blocking true (plasma) cholinesterase allows functionally enhanced levels of acetylcholine eluted from the nerve endings at the neuromuscular junction to competitively displace the NDNMB from the skeletal muscle receptor site (motor end-plate).

10.11.1 Quantitative neuromuscular transmission monitoring and treatment: train-of-four

Train-of-four (TOF) ratio > 0.90 → Reversal not required

TOF ratio 0.4–0.9 → Neostigmine 0.015–0.025 mg kg^{-1}, not to exceed 5 mg

TOF ratio < 0.4 or TOF count 2–3 → neostigmine 0.02–0.05 mg kg^{-1}, not to exceed 5 mg

TOF ratio 0 → delay reversal to TOF count of 2

10.11.2 Qualitative neuromuscular transmission monitoring and treatment: peripheral nerve stimulator

Four twitches with no fade → neostigmine 0.015–0.025 mg kg^{-1}, not to exceed 5 mg

Four twitches with fade → neostigmine 0.04 mg kg^{-1}, not to exceed 5 mg

One to 3 twitches → neostigmine 0.05 mg kg^{-1}, not to exceed 5 mg

No twitches → delay reversal to TOF count of 2

Reversal effect of neostigmine usually appears within ~1–2 min, with a maximum effect in about 6–10 min [23]. Since administration of neostigmine alone results in severe bradycardia, bronchospasm, and pathologic small bowel contraction, a parasympatholytic muscarinic blocking agent, such as atropine or glycopyrrolate, must be simultaneously administered. Administering neostigmine to a patient who is already reversed will result in neuromuscular transmission failure and skeletal muscle weakness, similar to a depolarizing succinylcholine block. In obese patients, recovery to a TOF ratio > 0.90 is slow when aminosteroid-based NDMNBs (vecuronium and rocuronium) are administered on the basis of actual (real) body weight [23].

Sugammadex is a cyclodextrin molecule that encapsulates and inactivates rocuronium and vecuronium [24, 25]. As a result, any degree of neuromuscular block produced by these agents can be rapidly and completely reversed without undesirable autonomic effects on the heart, lungs, or gut. The effective dose of sugammadex is between 1–16 mg kg^{-1}, depending on the magnitude of the block prior to reversal. For partial non-depolarizing blocks, sugammadex, 2 mg kg^{-1} should be given and for complete blocks, 4 mg kg^{-1} should be administered. For rapid reversal of a rapid sequence intubating dose of rocuronium or vecuronium, 16 mg kg^{-1} is considered appropriate. Sugammadex functionally renders rocuronium and vecuronium ultra-short acting muscle relaxants, and as such, may displace succinylcholine. In awake volunteers, rare side effects of sugammadex include hypotension, coughing, nausea, vomiting, dry mouth, and abnormal smell [25]. Very rarely, prolonged QTc interval occurs. By virtue of its consistent and dependable pattern of short reversal time, regardless of dose of NDMNBs, the need for neuromuscular monitoring may diminish or be abandoned completely in the operating room [24].

10.12 Brain function monitoring

The term awareness refers to situations in which either implicit or explicit recall of intra-anesthetic events occurs. Implicit recall refers to memory of conscious events, while explicit recall refers to subconscious memory [26]. In everyday anesthetic practice we approximate depth of anesthesia by assessment of sympatho-adrenal response to noxious stimuli. Signs of abrupt increase in heart rate (HR) and BP with incision, for example, prompt us to increase the dose of inhalation anesthetic or add more opioid to the regimen. While these maneuvers may be effective, increasing the depth of anesthesia can result in serious depression of cardiovascular homeostasis and brain function. EEG-based brain function monitors have been introduced to optimize the dose of anesthetic agents by monitoring electrical equivalents of levels of awareness.

10.12.1 Bispectral index

Bispectral index (BIS) monitoring purportedly reduces the incidence of recall under anesthesia by providing normalized numeric equivalents of EEG depth of consciousness. The BIS monitors accomplish this by providing various empirically based numeric ranges of levels of consciousness [27].

Awake: 100→80
Light hypnotic state: 80→60
Moderate hypnotic state: 60→40
Deepening of anesthesia: 40→30
Near suppression of cortical activity: 30→10
Cortical silence: 10→0

Experience utilizing BIS monitoring in the MO has generally been positive [28, 29]. During anesthesia, BIS-guided level of anesthesia versus MAP/HR-guided anesthesia with BIS monitoring showed that the latter approach resulted in greater depth of anesthesia [30]. A meta-analysis of 20 studies in 4056 mostly non-bariatric patients demonstrated that BIS-guided anesthesia beneficially reduced intraoperative propofol requirements, MAC requirements of inhalational agents, and was associated with more rapid recovery from anesthesia and earlier discharge from the PACU [31].

10.12.2 Paradoxical changes using BIS monitoring

Different anesthetic agents cause paradoxical directional changes in BIS awareness levels [32]. N_2O elimination can actually register as increasing level of unconsciousness (↓BIS) and administration of ketamine, isoflurane, and halothane can produce paradoxical increases in BIS. Equally perplexing is that BIS values are not the same for equipotent concentrations of inhaled anesthetics. For example, a mean BIS value of 57 with halothane was significantly higher than a mean BIS value of 32–33 for equipotent concentrations of sevoflurane or isoflurane. Equally disturbing is that large doses of opioids do not change BIS levels, even though patients may be unconscious and in an anesthetic state. However, when opioids are given before or in conjunction with propofol, smaller doses of propofol are required to achieve clinical anesthesia, but at a spuriously high BIS level. Thus, BIS values do not reflect the actual level of depression in consciousness and anesthetic state, which can lead to propofol overdose. Bispectral index values can also be spuriously lowered by the simple administration of neuromuscular blocking agents. Since muscle relaxants do not, per se, alter consciousness and do not provide analgesia or anesthesia, BIS values should not be exclusively relied upon using techniques based on total intravenous anesthesia or minimalist general anesthetic inhalation techniques [33].

In a study group of approximately 2000 patients, equally divided between those assigned to BIS-guided anesthesia and those assigned to end-tidal gas-guided anesthesia, no difference was found in the amount of volatile anesthetic gases administered or the incidence of awareness. Awareness under anesthesia occurred even when BIS values and end-tidal anesthesia gas concentrations were within the target ranges. This study did not support the routine use of BIS monitoring in standard anesthetic practice. It did, however, recommend its use in cases where high risk for awareness is suspected [34].

The decision to use BIS monitoring in MO patients undergoing general anesthesia, and especially total intravenous anesthesia, is still a matter of choice. The most recent practice advisory from the American Society of Anesthesiologists Task Force on Intraoperative Awareness has not declared the use of BIS monitoring a standard of care [35]. Bispectral index monitoring can be considered in conjunction with signs of sympathoadrenal stimulation, including heart rate and BP (in the absence of β-blockade), and other signs of inadequate anesthesia, such as tearing and diaphoresis for monitoring the first clues to the level of anesthesia.

10.13 Does monitoring improve mortality due to anesthesia?

Since the first reports studying deaths associated with anesthesia in the mid portion of the last century only

moderate statistical improvement in mortality has occurred [36]. These findings seem quite unbelievable given the explosive advances in monitoring over the past 40-year-period. Monitoring pulse oximetry, now a universal standard of care is able to detect rapid changes in arterial oxygen saturation. Yet, surprisingly, no prospective studies assessing outcome using pulse oximetry have shown improvement in reduction of anesthetic deaths due to arterial hypoxemia [37]. While end-tidal capnography is another acknowledged standard of care, there are no studies showing that it improves outcome (i.e., death under anesthesia). So what is it that impairs our ability to reduce anesthesia-related deaths to near zero? The answer partially resides with the patients themselves; those with higher American Society of Anesthesiologists (ASA) scores (i.e., ASA III and IV), extremes of age, emergency and trauma surgery, peri-operative adverse events (myocardial infarction, respiratory failure, etc.), and post-operative ICU admissions are markers of increased mortality, regardless of anesthetic management and monitoring. Other risk factors involve the type of anesthesia administered and hypothermia [38].

With respect to the MO patient, it is unknown what a incidence of death is due to anesthesia. When dealing with simple bariatric procedures in otherwise healthy individuals, the anesthesia mortality rate is probably very low. However, in the super-obese patient undergoing complicated surgery, with an anticipated protracted post-operative course, anesthesia-related deaths due to cardiac and/or respiratory failure are probably much higher.

The reduced incidence of death due directly to anesthesia is in all probability a result of multiple factors, including improved technologic diagnostic systems and proper interpretation of the information provided. Coupled with greater diagnostic capability, improved anesthesia delivery systems, a plethora of airway intubation tools, superior inhalation, and intravenous anesthetics, greater appreciation of the physiologic systems being interrogated and improved medications to favorably alter pathologic perturbations, modern anesthesia is truly in the forefront of patient safety.

References

1. Araghi A, Bander JJ, Guzman JA. Arterial blood pressure monitoring in overweight critically ill patients: invasive or noninvasive? *Crit Care* 2006; **10**: R64.
2. Janelle GM, Gravenstein N. An accuracy evaluation of the T-Line Tensymeter (continuous noninvasive blood pressure management device) versus conventional invasive radial artery monitoring in surgical patients. *Anesth Analg* 2006; **102**: 484–90.
3. Gelman S. Venous function and central venous pressure; a physiologic story. *Anesthesiology* 2008; **108**: 735–48.
4. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. *Chest* 2008; **134**: 172–8.
5. Bauer P, Reinhart K, Bauer M. Significance of venous oximetry in the critically ill. *Med Intensiva* 2008; **32**: 134–42.
6. Halpern SD, Taichman DB. Misclassification of pulmonary hypertension due to reliance on pulmonary capillary wedge pressure rather than left ventricular end-diastolic volume pressure. *Chest* 2009; **136**: 37–43.
7. Cannesson M, Desebbe O, Rosamel P, *et al*. Pleth variablility index to monitor the respiratory variations in the pulse oximeter plethysmographic waveform and predict fluid responsiveness in the operation room. *Br J Anaesth* 2008; **101**: 200–6.
8. Michard F. Changes in arterial pressure during mechanical ventilation. *Anesthesiology* 2005; **103**: 419–28.
9. Westphal G, Garrido AP, Almeida DP, *et al*. Pulse pressure respiratory variations as an early marker of cardiac output fall in experimental hemorrhagic shock. *Artif Organs* 2007; **31**: 284–9.
10. Gupta A, Lawrence AT, Krishnan K, *et al*. Current concepts in the mechanisms and management of drug-induced QT prolongation and torsade de pointes. *Am Heart J* 2007; **153**: 891–9.
11. Chang DJ, Kweon TD, Nam SB, *et al*. Effects of fentanyl pretreatment on the QTc interval during propofol induction. *Anaesthesia* 2008; **63**: 1056–60.
12. Karagoz AH, Basgul E, Celiker V, *et al*. The effect of inhalation anesthetics on QTc interval. *Eur J Anaesthesiol* 2005; **22**: 171–4.
13. Sprung J, Whalley DG, Falcone T, *et al*. The effects of tidal volume and respiratory rate on oxygenation and respiratory mechanics during laparoscopy in morbidly obese patients. *Anesth Analg* 2003; **97**: 268–74.
14. Perilli V, Sollazzi L, Modesti C, *et al*. Comparison of positive end-expiratory pressure with reverse Trendelenburg position in anesthetized morbidly obese patients undergoing bariatric surgery: effects on hemodynamics and gas exchange. *Obes Surg* 2003; **13**: 605–9.
15. Maniscalco M, Zedda A, Faraone S, *et al*. Evaluation of a transcutaneous carbon dioxide monitor in severe obesity. *Intensive Care Med* 2008; **34**: 1340–4.
16. Belzberg H, Wo CC, Demetriades D, *et al*. Effects of age and obesity on hemodynamics, tissue oxygenation, and outcome after trauma. *J Trauma* 2007; **62**: 1192–200.

17. Yu M, Morita SY, Daniel SR, *et al*. Transcutaneous pressure of oxygen: a noninvasive and early detector of peripheral shock and outcome. *Shock* 2006; **26**: 450–6.
18. Stein N, Matz H, Schneeweiss A, *et al*. An evaluation of a transcutaneous and an end-tidal capnometer for noninvasive monitoring of spontaneously breathing patients. *Resp Care* 2006; **51**: 1162–6.
19. Sakata DJ, Matsubara I, Gopalakrishnan NA, *et al*. Flow-through versus sidestream capnometry for detection of end-tidal carbon dioxide in the sedated patient. *J Clin Monit Comput* 2009; **23**: 115–22.
20. Sessler DI. Temperature monitoring and perioperative thermoregulation. *Anesthesiology* 2008; **109**: 318–38.
21. Rajapopalan S, Mascha E, Na J, *et al*. The effects of mild postoperative hypothermia on blood loss and transfusion requirement. *Anesthesiology* 2008; **108**: 71–7.
22. Kopman AF, Eikermann M. Antagonism of non-depolarizing neuromuscular block: current practice. *Anaesthesia* 2009; **64**(Suppl. 1): 22–30.
23. Suzuki T, Masaki G, Ogawa S. Neostigmine-induced reversal of vecuronium in normal weight, overweight and obese female patients. *Br J Anaesth* 2006; **97**: 160–3.
24. Caldwell JE, Miller RD. Clinical implications of sugammandex. *Anaesthesia* 2009; **64**(Suppl 1): 66–72.
25. Naguib M. Sugammadex: another milestone in clinical neuromuscular pharmacology. *Anesth Analg* 2007; **104**: 575–81.
26. Drummond JC. Monitoring depth of anesthesia with emphasis on the application of the bispectral index and the middle latency auditory evoked response to the prevention of recall. *Anesthesiology* 2000; **93**: 876–82.
27. Dahaba AA. Different conditions that could result in the bispectral index indicating an incorrect hypnotic state. *Anesth Analg* 2005; **101**: 765–73.
28. Pandazi A, Bourlioti A, Kostopanagiotou G. Bispectral index (BIS) monitoring in morbidly obese patients undergoing gastric bypass surgery: experience in 23 patients. *Obes Surg* 2005; **15**: 58–62.
29. Gaszynski T, Strzelczyk J, Machala W, *et al*. Reduction in total propofol consumption in morbidly obese patients during general anesthesia due to BIS monitoring. *Obes Surg* 2005; **15**: 1084–5.
30. White PF, Ma H, Tang J, *et al*. Does the use of electroencephalographic bispectral index or auditory evoked potential index monitoring facilitate recovery after desflurane anesthesia in the ambulatory setting? *Anesthesiology* 2004; **100**: 811–7.
31. Punjasawadwong Y, Boonjeungmonkol N, Phongchiewboon A. Bispectral index for improving anesthetic delivery and postoperative recovery. *Cochrane Database Syst Rev*. 2007 Issue 4: CD003843.
32. Lemmens HJ, Brodsky JB. General anesthesia, bariatric surgery, and the BIS monitor. *Obes Surg* 2005; **15**: 63.
33. Ekman A, Stalberg E, Sundman E, *et al*. The effect of neuromuscular block and noxious stimulation on hypnosis monitoring during sevoflurane anesthesia. *Anesth Analg* 2007; **105**: 688–95.
34. Avidan MS, Zhang L, Burnside BA, *et al*. Anesthesia awareness and the Bispectral index. *N Engl J Med* 2008; **358**: 1097–108.
35. American Society of Anesthesiologists Task Force on Intraoperative Awareness. *Anesthesiology* 2006; **104**: 847–64.
36. Brodsky JB. What intraoperative monitoring makes sense? *Chest* 1999; **115**(5 Suppl): 101S–5S.
37. Pedersen T, Moller AM, Pedersen BD. Pulse oximetry for perioperative monitoring: systematic review of randomized, controlled trials. *Anesth Analg* 2003; **96**: 426–31.
38. Fecho K, Lunney AT, Boysen PG, *et al*. Postoperative mortality after inpatient surgery: incidence of risk factors. *Ther Clin Risk Manag* 2008; **4**: 681–8.

Chapter 11

Effects of obesity on anesthetic agents

Hendrikus J.M. Lemmens and Jerry Ingrande

11.1 Introduction

Morbid obesity alters pharmacokinetics (PK) and time course of drug response. If obesity also alters the physiology or pathophysiology of the condition to be treated, then the pharmacodynamics (PD) of the drug will be altered as well. In general, anesthetic drugs have a narrow margin of safety due to their cardiovascular and respiratory side effects. However, in MO patients, whose cardiovascular and respiratory systems are deranged, the margin of safety is even smaller, and incorrect dosing may increase the rate of peri-operative complications. Rational peri-operative anesthetic drug selection and administration require knowledge of how morbid obesity interacts with commonly used drugs. In this chapter we review several factors that affect PK and PD of anesthetic agents in the obese population, we specify certain dosing scalars, and we relate our current knowledge of obesity's effects on the clinical pharmacology of specific drugs that produce or reverse anesthesia.

11.2 Pharmacokinetics and pharmacodynamics of anesthetic agents in obese patients

Obesity is associated with several factors that can affect the PK and PD of anesthetic agents [1]: increased cardiac output (CO) [2], increased lean body weight (LBW) [3], increased fat mass [4], increased extra cellular fluid volume [5], liver and kidney abnormalities, and increased splanchnic blood flow [6]. In addition [7], plasma protein concentration and the binding of drugs to plasma proteins may be different. However, obesity does not alter either absorption or bioavailability, despite increased splanchnic blood flow.

The first factor is an obese patient's increased CO. Cardiac output affects the early PK (front-end kinetics) of drug distribution and dilution in the first minutes after administration. Traditional mammillary compartment models assume that drugs mix instantaneously in the central compartment and then decline according to a multiexponential disposition function. Because these traditional models underestimate early peak concentrations, they cannot characterize how changes in early distribution affect dose requirements. Two other models – physiologic PK and recirculatory multicompartment models – can accurately describe the effects of variables such as CO on early drug distribution. They provide invaluable insights into factors affecting the dose requirement of intravenous induction agents. For example, Price's physiologic model explains the reduced dose requirements of thiopental in hypovolemic patients as follows: the decreased CO associated with hypovolemia greatly increases the fraction of thiopental dose distributed to the brain and greatly reduces the rate of redistribution [1]. Wada's more sophisticated physiologic model describes how changes in body composition and blood flow affect the dose requirements of thiopental, fentanyl, alfentanil and midazolam [2–4]. An obese subject's increased CO requires administration of a thiopental dose 46% higher than would be required for an average-size person to attain the same peak-plasma concentrations.

The second factor is increased LBW. Although the LBW/total body weight (TBW) ratio is lower in obese subjects than in normal weight subjects, obese patients' LBW exceeds that of normal weight patients, accounting for 20–40% of the obese patient's excess body weight. The body's metabolic processes and clearance of drugs occur in lean tissues; numerous PK studies have demonstrated absolute clearance is greater in obese than in non-obese subjects, increasing non-linearly with TBW. For a variety of drugs Han *et al.* demonstrated that clearance correlates linearly with LBW, implying that drug clearance is similar after normalizing for LBW [5]

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and also implying that LBW should be considered a key factor when adjusting a maintenance drug dose for a MO patient. In addition, in the MO patients a higher correlation between CO and LBW exists than between CO and fat tissue mass [6], suggesting the significance of LBW not only for determining maintenance dosing, but also for determining loading and induction doses.

The third factor is increased fat mass. In a normal weight patient, blood flow to fat equals 5% of the CO; in an obese patient it equals only 2% of CO, because the increased fat mass is significantly less perfused. Because tissue blood flow is a primary determinant of drug uptake, decreased fat perfusion may explain why the volume of distribution of lipophilic agents does not increase proportionally to the increased fat mass. For example, the distribution volume of propofol is similar when normalized for TBW in obese and non-obese subjects.

The fourth factor is increased extra-cellular fluid volume. Because adipose tissue's water content is almost completely extra-cellular, in obese patients extra-cellular fluid volume and the ratio of extra- to intra-cellular fluid volume are increased, thereby increasing the distribution volume of hydrophilic substances, such as muscle relaxants.

The fifth factor is liver and kidney abnormalities. Non-alcoholic steatohepatitis (NASH, "fatty hepatitis"), with or without liver dysfunction, is extremely common in obese patients [7]. Histologic abnormalities are present in the livers of as many as 90% of MO patients, although pre-operative liver function tests do not reflect the actual severity of liver dysfunction. Alanine aminotransferase (ALT) is the most frequently elevated liver enzyme. The effect of NASH on clearance of anesthetic drugs has not been studied, but it is probably insignificant.

The sixth factor is increased splanchnic blood flow. Obesity is associated with increased renal blood flow and increased glomerular filtration rate (GFR). Renal clearance of drugs increases with increased LBW. The most common renal abnormality seen is proteinuria.

Finally, plasma protein concentration and the binding of drugs to plasma proteins also affect the PK/PD of anesthetics. Pharmacologic effects are believed to be related to the concentration at the site of action. It is the unbound concentration rather than the total plasma concentration that is in equilibrium with the concentration at the site of action. Thus, variations in protein binding between patients may result in the need for different total plasma concentrations to achieve the same effect, even though the unbound concentrations may be similar. This is especially true for highly protein-bound drugs. It is possible that differences in protein binding may contribute to PD variability. The major plasma proteins are alpha$_1$-acid glycoprotein which binds basic drugs such as opioids, and albumin which binds acidic drugs such as thiopental, propofol and etomidate. Alpha$_1$-acid glycoprotein is an acute-phase protein that may be increased in patients with a chronic inflammatory state such as obesity. The concentration of albumin or drug binding to albumin is not altered by obesity.

11.3 Dosing scalars

In general, doses of drugs are individualized (scaled) according to body weight or size and a patient's condition. A dosing scalar should also take into account such body-composition factors as age and gender, and, for the MO obese patient, changes in body composition that occur with obesity. Body-composition scalars relevant to obese patients include TBW, ideal body weight (IBW), % ideal body weight (%IBW), body mass index (BMI), body surface area (BSA), adjusted body weight (ABW), predicted normal weight, and LBW, Table 11.1).

11.3.1 Total body weight

Dosing recommendations in package inserts, which are based upon kilograms of TBW, are valid for normal weight patients of varying sizes. However, in MO patients, adipose tissue and lean body mass do not increase proportionally (Figure 11.1). Instead, fat tissue increases proportionally with TBW, but the percentage of lean body tissue per kg of TBW decreases. These changes alter a drug's distribution and require that obese patients' doses be individualized accordingly to other dosing scalars.

11.3.2 Ideal body weight and % ideal body weight

Derived from data collected by the Metropolitan Life Insurance Company of New York, IBW describes the ideal weight associated with maximum life expectancy for a given height and body frame. Before BMI was used to define obesity, obesity was defined as TBW 20% greater than IBW. Many similar IBW equations exist (the most commonly used one described by Devine). Although IBW differentiates genders, it has two chief disadvantages: it indicates all patients of the same height should receive the same dose, and it does not take into account the changes in body composition

Table 11.1 Dosing scalars other than total body weight (TBW, kg)

Scalar	Derivation
Ideal body weight (kg)	Tables considering height, gender and frame size. Devine's estimation: 45.4 + 0.89 × (HT(cm) – 152.4) × 4.5 (if male)
Body mass index (kg m^{-20})	TBW/HT(m^2)
Body surface area (m^2)	Mosteller's adaptation: √[(HT(cm) × TBW)/3600]
Adjusted body weight (kg)	IBW + CF × (TBW-IBW) CF = correction factor
Predicted normal weight (kg)	Males: 1.57 × TBW – 0.0183 × BMI × TBW – 10.5 Females: 1.75 × TBW – 0.0242 × BMI × TBW – 12.6
Lean body weight (kg)	Males: 9270 × TBW/(6680 + 216 × BMI) Females: 9270 × TBW/(8780 + 244 × BMI)

HT, height.

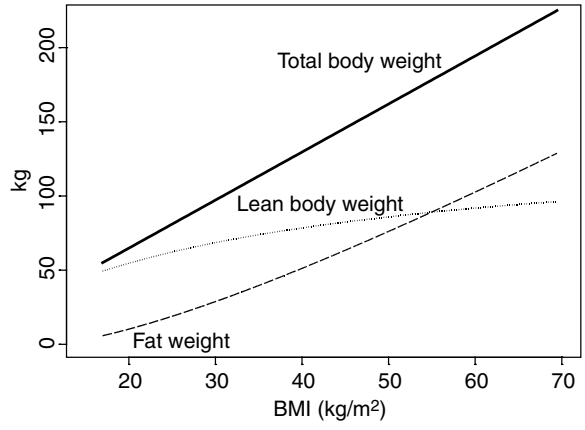


Figure 11.1 Schematic of total body weight, fat weight and lean body weight at different BMIs in a standard height male.

associated with obesity. Therefore, IBW and %IBW (the ratio of TBW to IBW) are illogical dosing scalars for an obese patient.

11.3.3 BMI

The ratio of TBW to height in meters squared is the standard metric used to classify obesity. However, because BMI cannot differentiate between fat and muscle mass, patients with a large muscle mass would receive the same dose as those with a large fat mass.

11.3.4 Body surface area

Body surface area is the gold-standard metric used to determine dosing of chemotherapeutic agents. Equations to calculate BSA, which contain TBW and height, are derived from regression on anatomic measurements. Mosteller's equations are the most widely used (Table 11.1). Body surface area is a disadvantageous scalar for dosing obese patients, because it fails to consider gender or to distinguish between fat and muscle mass. Moreover, in clinical practice doses of chemotherapeutics are capped at a BSA of 2 m^2.

11.3.5 Adjusted body weight

The ABW scalar was intended to normalize (correct) the increased volume of distribution in obese patients. To calculate ABW, some fixed proportion of the excess weight is added to the patient's IBW. Since physicochemical properties and distribution volumes of drugs differ, ABW should be determined for each drug. Servin *et al.* arbitrarily used 0.4 of the excess weight as a correction factor for calculating propofol infusion rates in obese patients [8]. However, they found that using this factor (compared with using TBW) did not improve accuracy of the predicted propofol plasma concentrations.

11.3.6 Predicted normal weight

Predicted normal weight of the obese patient is the sum of LBW and predicted normal fat mass. Its application as a dosing scalar in the obese patient is unclear.

11.3.7 Lean body weight

Finally, lean body weight is TBW minus body fat weight. When TBW increases, LBW also increases taking into account changes in body composition associated with obesity depending on TBW, height and gender. Lean body weight is also significantly correlated with CO, an important factor of the early distribution kinetics. Almost all metabolic activity in the body occurs in the lean tissues, and clearance increases linearly with LBW. Therefore, LBW as a dosing scalar is valid across all body compositions. However, few PK studies in obese patients have considered this scalar, presumably because formulas to accurately estimate LBW, especially in obese patients have been problematic. James' LBW equations, derived in patients with BMIs only up to 43 kg m^{-2}, should not be used in larger patients [9]. For example, if James' equations use input data from patients whose TBW exceeds 120 kg, their LBW will decrease, even reaching negative values in very large patients. However, in 2005 Janmahasatian derived LBW equations for patients ranging between 40 and 220 kg. These LBW equations have accurate predictive properties when compared with LBW derived from dual energy X-ray absorptiometry [10]. Figure

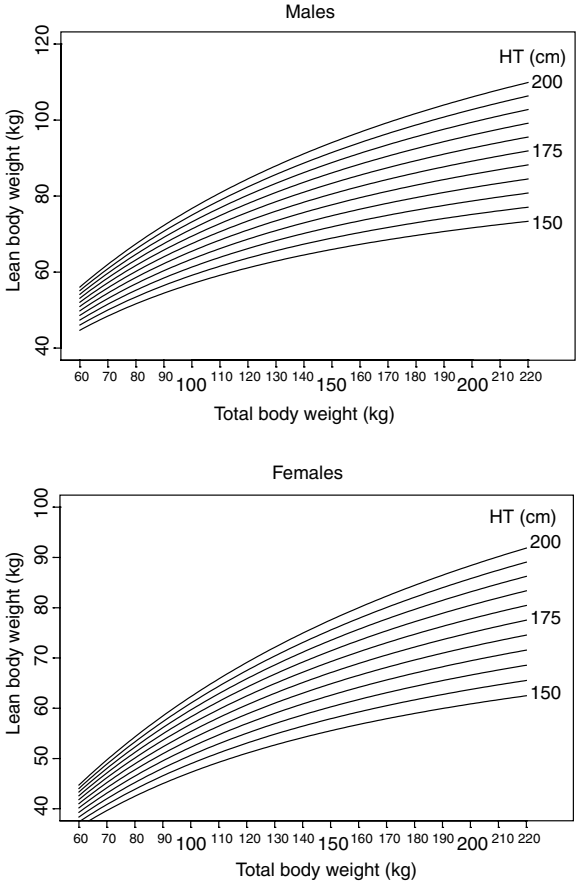


Figure 11.2 Estimated lean body weight for males and females with weights between 60 and 220 kg and heights (HT) between 150 and 200 cm. Estimates are derived from the equations of Janmahasatian *et al.* [10].

11.2 shows the relation between TBW and LBW for a wide range of patients. This data can be used to easily approximate LBW.

11.4 Agents

11.4.1 Hypnotics

11.4.1.1 Thiopental

Thiopental is distributed rapidly from blood to tissues. After a single pass, 76% of thiopental distributes to highly perfused tissues such as the lung, brain, liver, heart kidney, gut, and pancreas. Two minutes after being administered, thiopental redistributes into muscle, resulting in depleted thiopental from the brain, and termination of its anesthetic effect. After 10 min the decline in plasma concentration is mainly due to uptake in fat and elimination by the liver. The fact

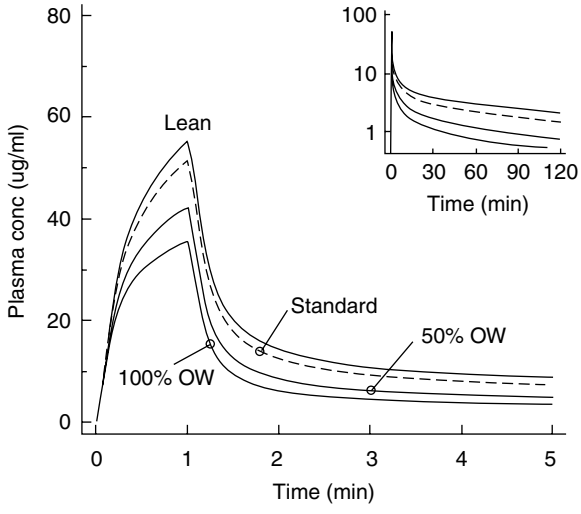


Figure 11.3 Predicted arterial thiopental concentrations after a 250 mg dose in subjects of different sizes: 50% excess weight (overweight), 100% excess weight (MO), and 15% underweight (lean). Adapted from: Ref. [2], with permission.

that increased CO is associated with morbid obesity significantly affects thiopental dose requirements in the obese. Figure 11.3 shows the predicted thiopental concentrations in patients of different sizes after a thiopental induction dose of 250 mg. Peak arterial concentration is 60% lower in a 100% overweight patient (BMI ~42 kg m^{-2}) than in a lean patient. During the first 5 min thiopental concentrations are 52% less in an overweight patient than in a lean subject; over 120 min concentrations are 73% less. Thiopental dose adjusted according to LBW results in the same peak plasma concentration as dose adjusted according to CO [2]. These data suggest one could justify dosing thiopental in the morbidly obese on the basis of either the higher CO or increased LBW. Although this dose adjustment will result in similar peak plasma concentrations, the increased CO and LBW will result in more rapid redistribution from the brain and a faster awakening time should be anticipated.

In a PK study in which patients received thiopental to induce anesthesia, absolute total body clearance was significantly larger in the obese (25 l h^{-1}) than in normal weight patients (11.9 l h^{-1}) [11]. When patients were normalized for TBW there was no difference in clearance. Therefore, if thiopental is administered long term, for example to treat an epileptic state or a damaged brain, obesity will not affect the thiopental's total dose or steady-state concentration when the drug is administered on a per kg TBW basis. However, the steady-state volume of distribution is significantly larger in the obese (7.9 l kg^{-1}) than in the normal weight patients (4.7 l kg^{-1}), resulting

in a significantly prolonged elimination half-life for obese patients (27.8 h) compared to lean patients (6.3 h).

11.4.1.2 Propofol

In current anesthetic practice propofol is the induction agent of choice for obese patients. Like thiopental, propofol distributes fast from blood to tissues. Cardiac output has a significant effect on peak-plasma concentration and duration of effect. After a bolus dose of 2 mg kg^{-1}, propofol's peak-plasma concentration is inversely related to CO, and for COs of 8.5, 5.5, and 2.5 l min^{-1}, recovery of consciousness is predicted to occur at 2.9, 8.6, and 18.7 min, respectively [12,13]. However, CO does not affect how long it takes to lose consciousness. Lean body weight is a more appropriate weight-based scalar than TBW for propofol induction of general anesthesia in MO patients. MO patients in whom anesthesia was induced with a propofol infusion based on LBW required similar doses of propofol and had similar times to loss of consciousness compared to non-obese control patients given a propofol infusion based on TBW. These data suggest one could justify dosing propofol on the basis of the higher CO or increased LBW associated with obesity. In a PK study of eight obese patients who were administered relatively low-rate propofol infusions, volume of distribution and clearance increased with TBW half-life was unchanged. When obese patients were normalized for TBW, clearance and volume of distribution were the same as for lean subjects [8], a fact that suggests propofol dosage for maintenance infusions should be based on TBW. Some reports suggest that the induction dose of propofol should also be calculated according to TBW. However, the scientific basis for this is lacking.

The metabolic clearance of propofol is ten times faster than that of thiopental; propofol's clearance exceeds hepatic blood flow, indicating that propofol is also metabolized in extra-hepatic sites such as the kidney and lung. At subanesthetic doses propofol reduces the ventilatory response to hypercapnia and the ventilatory adaptation to hypoxia. The drug potentiates hypoxic pulmonary vasoconstriction. Propofol has antiemetic properties which are at least partly related to an inhibitory effect on the $5\text{-}HT_{3A}$ receptors. Propofol is a structural analog of the antioxidant vitamin E, and it may have a protective effect against ischemia and reperfusion injuries.

11.4.1.3 Etomidate

In hemodynamically unstable MO patients or patients with obesity cardiomyopathy, anesthesic induction with etomidate may be a better choice than either thiopental or propofol. In normal weight patients the standard etomidate induction dose is 0.3 mg kg^{-1} (the recommended induction dose range is 0.2–0.6 mg kg^{-1}). The time-to-recovery of consciousness is approximately 8 min after a dose of 0.3 mg kg^{-1}. Each 0.1mg kg^{-1} dose increase results in 100 sec longer duration of unconsciousness. Time-to-loss of consciousness is the same for etomidate as for thiopental and propofol. Etomidate's site effects are pain on injection, myoclonus, high incidence of post-operative nausea and vomiting, and transient inhibition of steroid synthesis which is probably clinical insignificant after a single dose. The PKs and PDs of etomidate in obese patient have not been studied. Given the PK similarities of etomidate, thiopental, and propofol, one could justify an induction dose adjusted according to LBW and anticipate a time-to-recovery of consciousness inversely related to CO.

11.4.1.4 Dexmedetomidine

Dexmedetomidine is a selective $alpha_2$-adrenoreceptor agonist with an $alpha_2$: $alpha_1$ ratio of 1600:1. Dexmedetomidine has anxiolytic, sedative, and analgesic effects. Respiratory depression is minimal, but dexmedetomidine potentiates the effect of opioids and benzodiazepines. The short distribution half-life (8 min) and relatively short elimination half-life (2 hours) make it suitable for titration by continuous infusion. The sympatholytic effect of dexmedetomidine decreases norepinephrine release, arterial blood pressure, and heart rate. These decreases may result in severe hypotension in hypovolemic patients and severe bradycardia in patients with heart block. Another side effect is dry mouth, an advantage if fiberoptic intubation is performed. Post-operatively, dexmedetomidine reduces shivering. During open gastric-bypass surgery when a loading dose of dexmedetomidine, 0.5 mcg kg^{-1}, given over 10 min followed by an infusion of 0.4 mcg^{-1} kg^{-1} h^{-1} was used instead of fentanyl to supplement desflurane, the result was significantly lower arterial blood pressure and heart rate, shorter time to extubation, lower pain scores, and less morphine use in the post anesthesia care unit [15]. During laparoscopic bariatric surgery a lower infusion rate of dexmedetomide (0.2 mcg^{-1} kg^{-1} min^{-1}) is recommended to reduce the risk of cardiovascular side effects [16].

11.4.2 Opioids

11.4.2.1 Fentanyl

Opioids effectively block somatic and autonomic responses during surgery. Fentanyl, the most commonly

used opioid, has an n-octanol water partition coefficient of 813, and a pKa of 8.4, resulting in an onset time of approximately 5 min. The higher CO in obese patients will result in significantly lower fentanyl concentrations in the early phase of distribution [3]. Also later on, PK parameters of normal-sized persons will over-predict measured fentanyl concentrations in obese patients. Shibutani *et al.* [17] showed clearance is higher in obese patients, increasing non-linearly with increasing TBW. They did not normalize clearance for LBW but derived a hypothetic "pharmacokinetic mass" increasing linearly with clearance. Interestingly, their derived "pharmacokinetic mass" is highly correlated to LBW and is presumably similar [5]. These data suggest loading and maintenance doses of fentanyl should be based on LBW. However, because obesity increases the probability of hypoxia in the peri-operative period, fentanyl, and other opioids should be carefully titrated according to individual patient need.

11.4.2.2 Sufentanil

Sufentanil, the most potent opioid, is highly lipophilic with an n-octanol water partition coefficient of 1754, a pKa of 8.0, and an onset time of approximately 5 min. Like fentanyl, PK parameters of normal-sized persons will over-predict measured sufentanil concentrations in MO patients [18]. Schwartz *et al.* reported in obese patients an increased absolute volume of distribution and an increased volume of distribution when normalized for IBW. Obesity also increased the elimination half life, while clearance was not significantly higher.

11.4.2.3 Alfentanil

The pKa of alfentanil is 6.5 and the n-octanol water partition coefficient is 129. Alfentanil has a fast onset time of approximately 1 min. The higher CO in obese patients will result in significantly lower alfentanil concentrations in the early phase of distribution [3]. Alfentanil is less lipid soluble than fentanyl or sufentanil and has a smaller volume of distribution. No data on the effects of obesity on the PKs of alfentanil have been published.

11.4.2.4 Remifentanil

Remifentanil is a fentanyl congener characterized by an ester structure, a pKa of 7.07 and n-octanol water partition coefficient of 17.9. These physicochemical properties result in a fast onset time of approximately 1 min. Plasma and tissue esterases hydrolyze remifentanil rapidly, resulting in an extraordinary high clearance (3 l min^{-1}) unaffected by hepatic or renal insufficiency.

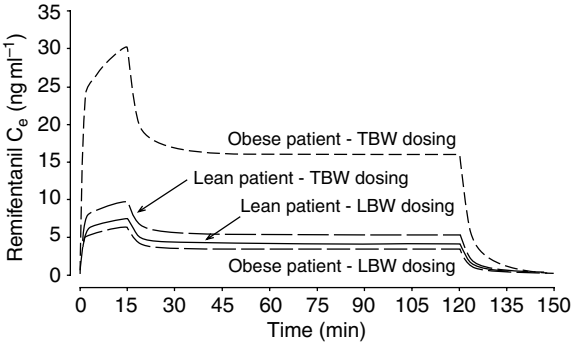


Figure 11.4 Simulated remifentanil effect site concentrations in a lean and an obese patient when dosed according to total body weight (TBW) or lean body mass (LBM). Reprinted from: [Ref. 19], with permission.

The fast onset time and high clearance make remifentanil especially suitable for administration by continuous infusion. Volumes and clearances not normalized for weight are similar in obese and non-obese patients, and do not correlate with TBW but do correlate significantly with LBW. Therefore, in the obese dosing of remifentanil based on TBW will result in concentrations higher than those needed for clinical purposes (Figure 11.4), and an increased incidence of side effects such as hypotension and bradycardia. Remifentanil dosing based on LBW results in plasma concentrations similar to those in normal weight subjects when dosed according to TBW [19]. After remifentanil has been discontinued, its effect terminates rapidly within 5–10 min. Therefore, when post-operative pain is anticipated, alternative analgesics should be administered prior to remifentanil's discontinuation. Rapid bolus administration may result in severe bradycardia and hypotension and, in awake or non-paralyzed patients, severe muscle rigidity.

11.4.3 Mode of administration of hypnotics and opioids

Target-controlled infusion (TCI), an anesthetic dosing technique developed during the last decades, is approved in Europe but not in the USA. It allows interactive drug dosing on the basis of common PK-PD models. Target-controlled infusion controls the anesthetic drug concentration in the blood or at the effect site, taking into account the hysteresis (time lag) between the drug entering the blood and then the effect site, and is helpful when different surgical stimuli occur in different surgical periods. Drug concentrations and drug types can be varied to suppress patients' responses to nociceptive stimulation. Target-controlled infusion

of hypnotics and opioids that titrate the target plasma concentration to the individual patient's responses may result in more stable anesthesia and a more rapid recovery. For example, during laparoscopic gastric banding procedures, TCI of remifentanil when compared to TCI of the longer-acting sufentanil, results in better hemodynamic stability of the former, no difference in recovery of respiratory function, but more pain in the first 2 hours post-operatively [20].

11.4.4 Inhalational anesthetics

11.4.4.1 Isoflurane

Because isoflurane is more lipophilic than either desflurane or sevoflurane, desflurane and sevoflurane have been marketed as the anesthetics of choice for obese patients when fast recovery from anesthesia is desired. However, obese and non-obese patients responded to commands equally rapidly (7 min) after 0.6 MAC isoflurane administration for procedures lasting 2–4 hours [21].

Theoretically, the solubility of potent inhaled anesthetics in fat and the increased BMI in obese patients interact to increase anesthetic uptake and to decrease the rate at which the delivered (FD) and inspired (FI) concentrations of an inhaled anesthetic approach a constantly maintained alveolar concentration (end-tidal or FA). This hypothesis implies that the effect of obesity would be greater with a more soluble anesthetic such as isoflurane versus desflurane. In other words, an increased BMI would increase anesthetic uptake and thus the need for delivered anesthetic to sustain a constant alveolar anesthetic concentration, particularly with a more soluble anesthetic. However, blood flow per kg of fat tissue decreases with increasing obesity [22]. Also, the time constants (the time to reach 63% of equilibrium) for equilibrium of isoflurane or desflurane with fat are 2110 and 1350 min, respectively [23]. The decreased fat perfusion and the long time constants will minimize the effect of increased fat tissue mass when isoflurane is used in routine clinical practice. Indeed, during routine surgical procedures the effect of BMI on isoflurane uptake was small and clinically insignificant [21]. The modest increased uptake in obese patients was attributed to increased uptake in the increased lean body mass. In addition, intertissue diffusion may be increased in obese patients. The time constants for highly perfused tissues such as kidney, intestines, liver, and heart are short – tissue/blood partition coefficients and tissue blood flows suggest time constants of a few minutes [23, 24]. These tissues quickly develop appreciable anesthetic partial pressures that can be transferred to adjacent fat (i.e., anesthetic can move from these tissues to fat) early in anesthesia. Thus, perirenal, mesenteric, omental, and pericardial fat – all of which are increased in obesity – may increase intertissue diffusion and add to the uptake of anesthetic.

11.4.4.2 Desflurane

Obese and non-obese patients responded to commands equally rapidly after 0.6 MAC desflurane administration for procedures lasting 2–4 hours [21]. The effect of BMI on desflurane uptake is insignificant [21]. In both obese and non-obese patients, emergence and recovery will be faster with desflurane than with isoflurane [21, 25]. Several studies in obese patients have compared some kinetic aspects of desflurane and sevoflurane with variable results, perhaps because of different experimental conditions [26–31]. For example, Strum *et al.* [26], De Baerdemaeker *et al.* [27], and La Colla *et al.* [30] showed that MO patients emerge from anesthesia more rapidly after desflurane than after sevoflurane anesthesia. On the other hand, Arain *et al.* [28] and Vallejo *et al.* [29] did not find a difference in time-to-awakening between patients receiving desflurane or sevoflurane.

11.4.4.3 Sevoflurane

Sevoflurane appears to provide a slightly more rapid uptake and elimination of anesthetic in MO patients than does isoflurane [32].

The safety of sevoflurane in patients with impaired renal function has been widely studied and debated. Sevoflurane is metabolized by the liver to hexa-fluoro-isopropanol and inorganic fluoride. Fluoride concentrations greater than 50 mmol l^{-1} can be nephrotoxic. Sevoflurane is degraded to compound A by carbon dioxide absorbers containing a strong base such as barium hydroxide lime or to a lesser extent by soda lime. Reductions in fresh gas flow, as well as an increase in temperature in the gas mixture, will increase compound A concentrations. Albuminuria, glucosuria, and enzymuria are associated with inhaled doses of compound A greater than 160 ppm h^{-1}. In the few studies in patients with renal impairment no evidence of further worsening of renal function could be demonstrated after sevoflurane administration. However, the safety of sevoflurane in patients with impaired renal function is unclear.

11.4.5 Muscle relaxants

11.4.5.1 Succinylcholine

The depolarizing muscle relaxant succinylcholine has rapid onset and short duration of action, properties ideal for MO patients because hemoglobin desaturation occurs rapidly after apnea, and intubation of the trachea must be accomplished quickly. If difficulty is encountered, the short duration of action will result in fast recovery of neuromuscular blockade and resumption of spontaneous ventilation (Figure 11.5). In MO patients the concentration of pseudocholinesterase, the enzyme that metabolizes succinylcholine, is increased [33]. Because the level of plasma pseudocholinesterase activity and the volume of extracellular fluid determine the duration of action of succinylcholine, and both of these factors are increased in obesity, morbidly obese patients have larger absolute succinylcholine dose requirements than average-weight patients. When succinylcholine administration is based upon TBW, rather than upon LBW or IBW, a more profound neuromuscular block and better intubating conditions are achieved [34]. The incidence of post-operative myalgia in bariatric patients is low and usually of no clinical significance [34].

Once the neuromuscular reversal agent sugammadex becomes available, a fast-acting, non-depolarizing muscle relaxant such as rocuronium will become a safe alternative to succinylcholine. With sugammadex, reversal will be obtained immediately, effectively controlling time of paralysis. Until that time, succinylcholine remains the drug of choice for tracheal intubation in MO patients.

11.4.5.2 Rocuronium

Non-depolarizing muscle relaxants such as rocuronium are only weakly or moderately lipophilic, because the quaternary ammonium group they contain makes these molecules as a whole, highly ionized at physiologic pH. The poor lipophilicity limits distribution outside the extracellular fluid space. The effect of the increased extracellular fluid volume in the obese patient on the pharmacology of muscle relaxants is poorly understood. In one study, after investigators had administered rocuronium, 0.6 mg kg^{-1}, they found that PK parameters and spontaneous recovery to 75% of twitch height were similar in obese and lean patients [35]. In another study, investigators administered rocuronium to MO patients on the basis of both TBW and IBW, finding that the duration of action

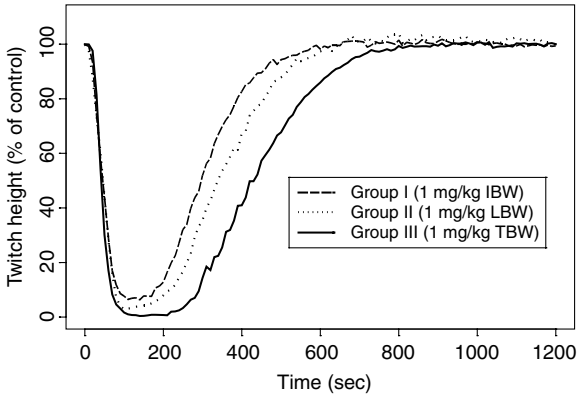


Figure 11.5 Twitch height (mean values) versus time after succinylcholine administration. The dose of succinylcholine was 1.0 mg kg^{-1} ideal body weight (IBW) in Group I, 1.0 mg kg^{-1} lean body weight (LBW) in Group II, and 1.0 mg kg^{-1} total body weight (TBW) in Group III. In one third of the patients in Group I intubating conditions were rated poor. In contrast, none of the patients in Group III had poor intubating conditions. Adequate spontaneous ventilation recurs at 50% recovery of twitch height.

was more than double when rocuronium was dosed on TBW [36]. Therefore, they recommended basing rocuronium administration in the MO on IBW. Even so, because the reported recovery times for rocuronium and all other muscle relaxants are highly variable in obese patients, careful monitoring of the degree of neuromuscular blockade is recommended.

11.4.5.3 Vecuronium

Seven obese subjects receiving TBW-based 0.1 mg kg^{-1} vecuronium took 60% longer to recover from neuromuscular blockade than did seven normal weight control subjects, whose administered dosage was less [37]. However, PK parameters uncorrected for weight were similar between the two groups. The larger dose (and resulting higher vecuronium plasma concentration) administered to obese patients explains their prolonged recovery time. With higher doses, plasma concentration decreases more slowly than with smaller doses (plasma concentration rapidly declines), when recovery occurs earlier during the distribution phase. To avoid an overdose of vecuronium in the obese, basing administration on IBW is recommended [37].

11.4.5.4 Cisatracurium

Because cisatracurium is eliminated via Hoffman degradation, investigators have suggested it as the neuromuscular-blocking drug of choice for obese patients. They compared the duration of cisatracurium's action, when administered to both MO and normal weight

patients – on the basis of both TBW and IBW. They found that duration of action was prolonged in MO patients [38]. When cisatracurium was administered to both obese patients and normal weight patients according to IBW, its duration of action was shorter in the former than in the latter [38].

For atracurium when dosed based on TBW a prolonged duration of action in obese patients has been demonstrated as well [39].

11.4.5.5 Pancuronium

To maintain a constant 90% depression of twitch height, obese patients require significantly more pancuronium than non-obese patients [40]. However, when corrected for BSA, no differences in required amounts of pancuronium exist. Because BSA and extra cellular fluid volume are correlated, the greater amount of pancuronium necessary to produce adequate muscle relaxation in the MO is probably related to the increase in extra cellular fluid volume that occurs with increasing obesity. The kidneys excrete the majority of pancuronium and its active metabolites. To avoid postoperative residual neuromuscular blockade in MO patients, the shorter-acting, non-depolarizing, neuromuscular blockers – such as rocuronium, vecuronium or atracurium – are better choices than the long-acting pancuronium.

11.4.6 Reversal agents

11.4.6.1 Neostigmine

Neostigmine's reversal effect appears within 1–2 min; its maximum effect occurs within 6–10 min. If, at the peak, the antagonistic effect of neostigmine complete reversal is not obtained, further recovery is slow, depending on the balance between the waning reversal effect of neostigmine and spontaneous recovery. When vecuronium dosage is based on TBW and reversed with neostigmine, 0.04 mg kg^{-1}, at 25% recovery of twitch height, time to a train-of-four (TOF) ratio of 0.7 (inadequate reversal) is similar between normal weight and obese patients (3.8–4.8 min). However, recovery time to a TOF ratio of 0.9 (adequate reversal) is four times slower in the obese patient (25.9 min) than in the normal weight patient (6.9 min) [41]. Atracurium administered to obese patients based on TBW, is equally rapid reversed to a TOF ratio of 0.7 by neostigmine, 0.07 mg kg^{-1}, when compared to normal weight patients [42]. Neostigmine has a ceiling effect – higher doses only result in a faster onset of effect. The recommended dose is 0.04–0.08 mg kg^{-1}, not to exceed a total dose of 5 mg. The dose–response relationship of neostigmine in obese patients, however, has not been studied.

11.4.6.2 Sugammadex

Sugammadex is a new, selective, relaxant-binding agent designed to bind and encapsulate rocuronium and vecuronium with very high affinity. Sugammadex's binding decreases the concentration of neuromuscular blocking agent at the nicotinic receptor, resulting in reversal of neuromuscular blockade. The bound complex is excreted by the kidneys at a rate equal to that of glomerular filtration. Unlike neostigmine, sugammadex has no effect at the receptor level, and no hemodynamic or other side effects. After sugammadex is administered, it distributes rapidly in a small distribution volume equal to the extracellular fluid volume.

Sugammadex can reverse profound neuromuscular blockade. For example, after an intubating dose of rocuronium has been administered, sugammadex 16 mg kg^{-1} can provide immediate reversal; a dose of sugammadex 2–4 mg kg^{-1} can reverse an incomplete block. The dose–response relationship of sugammadex in the obese patient has not yet been investigated.

References

1. Price HL. A dynamic concept of the distribution of thiopental in the human body. *Anesthesiology* 1960; **21**: 40–5.
2. Wada DR, Bjorkman S, Ebling WF, *et al*. Computer simulation of the effects of alterations in blood flows and body composition on thiopental pharmacokinetics in humans. *Anesthesiology* 1997; **87**: 884–99.
3. Bjorkman S, Wada DR, Stanski DR. Application of physiologic models to predict the influence of changes in body composition and blood flows on the pharmacokinetics of fentanyl and alfentanil in patients. *Anesthesiology* 1998; **88**: 657–67.
4. Bjorkman S, Wada DR, Berling BM, Benoni G. Prediction of the disposition of midazolam in surgical patients by a physiologically based pharmacokinetic model. *J Pharm Sci* 2001; **90**: 1226–41.
5. Han PY, Duffull SB, Kirkpatrick CM, Green B. Dosing in obesity: a simple solution to a big problem. *Clin Pharmacol Ther* 2007; **82**: 505–8.
6. Collis T, Devereux RB, Roman MJ, *et al*. Relations of stroke volume and CO to body composition: the strong heart study. *Circulation* 2001; **103**: 820–5.
7. Moretto M, Kupski C, Mottin CC, *et al*. Hepatic steatosis in patients undergoing bariatric surgery and its relationship to body mass index and co-morbidities. *Obes Surg* 2003; **13**: 622–4.

8. Servin F, Farinotti R, Haberer JP, Desmonts JM. Propofol infusion for maintenance of anesthesia in morbidly obese patients receiving nitrous oxide. A clinical and pharmacokinetic study. *Anesthesiology* 1993; **78**: 657–65.
9. James W. *Research on Obesity*. London: Her Majesty's Stationery Office, 1976.
10. Janmahasatian S, Duffull SB, Ash S, *et al*. Quantification of lean bodyweight. *Clin Pharmacokinet* 2005; **44**: 1051–65.
11. Jung D, Mayersohn M, Perrier D, *et al*. Thiopental disposition in lean and obese patients undergoing surgery. *Anesthesiology* 1982; **56**: 269–74.
12. Upton RN, Ludbrook GL, Grant C, Martinez AM. CO is a determinant of the initial concentrations of propofol after short-infusion administration. *Anesth Analg* 1999; **89**: 545–52.
13. Upton RN, Ludbrook G. A physiologically based, recirculatory model of the kinetics and dynamics of propofol in man. *Anesthesiology* 2005; **103**: 344–52.
14. Barann M, Linden I, Witten S, Urban BW. Molecular actions of propofol on human 5-HT3A receptors: enhancement as well as inhibition by closely related phenol derivatives. *Anesth Analg* 2008; **106**: 846–57.
15. Feld JM, Hoffman WE, Stechert MM, *et al*. Fentanyl or dexmedetomidine combined with desflurane for bariatric surgery. *J Clin Anesth* 2006; **18**: 24–8.
16. Tufanogullari B, White PF, Peixoto MP, *et al*. Dexmedetomidine infusion during laparoscopic bariatric surgery: the effect on recovery outcome variables. *Anesth Analg* 2008; **106**: 1741–8.
17. Shibutani K, Inchiosa MA, Jr., Sawada K, Bairamian M. Accuracy of pharmacokinetic models for predicting plasma fentanyl concentrations in lean and obese surgical patients: derivation of dosing weight ("pharmacokinetic mass"). *Anesthesiology* 2004; **101**: 603–13.
18. Slepchenko G, Simon N, Goubaux B, *et al*. Performance of target-controlled sufentanil infusion in obese patients. *Anesthesiology* 2003; **98**: 65–73.
19. Egan TD, Huizinga B, Gupta SK, *et al*. Remifentanil pharmacokinetics in obese versus lean patients. *Anesthesiology* 1998; **89**: 562–73.
20. De Baerdemaeker LE, Jacobs S, Pattyn P, *et al*. Influence of intraoperative opioid on postoperative pain and pulmonary function after laparoscopic gastric banding: remifentanil TCI vs sufentanil TCI in morbid obesity. *Br J Anaesth* 2007; **99**: 404–11.
21. Lemmens HJ, Saidman LJ, Eger EI, 2nd, Laster MJ. Obesity modestly affects inhaled anesthetic kinetics in humans. *Anesth Analg* 2008; **107**: 1864–70.
22. Lesser GT, Deutsch S. Measurement of adipose tissue blood flow and perfusion in man by uptake of 85Kr. *J Appl Physiol* 1967; **23**: 621–30.
23. Yasuda N, Lockhart SH, Eger EI, 2nd, *et al*. Kinetics of desflurane, isoflurane, and halothane in humans. *Anesthesiology* 1991; **74**: 489–98.
24. Carpenter RL, Eger EI, 2nd, Johnson BH, *et al*. Pharmacokinetics of inhaled anesthetics in humans: measurements during and after the simultaneous administration of enflurane, halothane, isoflurane, methoxyflurane, and nitrous oxide. *Anesth Analg* 1986; **65**: 575–82.
25. Torri G, Casati A, Albertin A, *et al*. Randomized comparison of isoflurane and sevoflurane for laparoscopic gastric banding in morbidly obese patients. *J Clin Anesth* 2001; **13**: 565–70.
26. Strum EM, Szenohradszki J, Kaufman WA, *et al*. Emergence and recovery characteristics of desflurane versus sevoflurane in morbidly obese adult surgical patients: a prospective, randomized study. *Anesth Analg* 2004; **99**: 1848–53.
27. De Baerdemaeker LE, Struys MM, Jacobs S, *et al*. Optimization of desflurane administration in morbidly obese patients: a comparison with sevoflurane using an 'inhalation bolus' technique. *Br J Anaesth* 2003; **91**: 638–50.
28. Arain SR, Barth CD, Shankar H, Ebert TJ. Choice of volatile anesthetic for the morbidly obese patient: sevoflurane or desflurane. *J Clin Anesth* 2005; **17**: 413–9.
29. Vallejo MC, Sah N, Phelps AL, *et al*. Desflurane versus sevoflurane for laparoscopic gastroplasty in morbidly obese patients. *J Clin Anesth* 2007; **19**: 3–8.
30. La Colla L, Albertin A, La Colla G, Mangano A. Faster wash-out and recovery for desflurane vs sevoflurane in morbidly obese patients when no premedication is used. *Br J Anaesth* 2007; **99**: 353–8.
31. Casati A, Marchetti C, Spreafico E, Mamo D. Effects of obesity on wash-in and wash-out kinetics of sevoflurane. *Eur J Anaesthesiol* 2004; **21**: 243–5.
32. Torri G, Casati A, Comotti L, *et al*. Wash-in and wash-out curves of sevoflurane and isoflurane in morbidly obese patients. *Minerva Anestesiol* 2002; **68**: 523–7.
33. Bentley JB, Borel JD, Vaughan RW, Gandolfi AJ. Weight, pseudocholinesterase activity, and succinylcholine requirement. *Anesthesiology* 1982; **57**: 48–9.
34. Lemmens HJ, Brodsky JB. The dose of succinylcholine in morbid obesity. *Anesth Analg* 2006; **102**: 438–42.
35. Puhringer FK, Keller C, Kleinsasser A, *et al*. Pharmacokinetics of rocuronium bromide in obese female patients. *Eur J Anaesthesiol* 1999; **16**: 507–10.
36. Leykin Y, Pellis T, Lucca M, *et al*. The pharmacodynamic effects of rocuronium when dosed according to real body weight or ideal body weight in morbidly obese patients. *Anesth Analg* 2004; **99**: 1086–9.
37. Schwartz AE, Matteo RS, Ornstein E, *et al*. Pharmacokinetics and pharmacodynamics of

vecuronium in the obese surgical patient. *Anesth Analg* 1992; **74**: 515–8.

38. Leykin Y, Pellis T, Lucca M, *et al*. The effects of cisatracurium on morbidly obese women. *Anesth Analg* 2004; **99**: 1090–4.
39. Kirkegaard-Nielsen H, Helbo-Hansen HS, Lindholm P, *et al*. Anthropometric variables as predictors for duration of action of atracurium-induced neuromuscular block. *Anesth Analg* 1996; **83**: 1076–80.
40. Tsueda K, Warren JE, McCafferty LA, Nagle JP. Pancuronium bromide requirement during anesthesia for the morbidly obese. *Anesthesiology* 1978; **48**: 438–9.
41. Suzuki T, Masaki G, Ogawa S. Neostigmine-induced reversal of vecuronium in normal weight, overweight and obese female patients. *Br J Anaesth* 2006; **97**: 160–3.
42. Kirkegaard-Nielsen H, Lindholm P, Petersen HS, Severinsen IK. Antagonism of atracurium-induced block in obese patients. *Can J Anaesth* 1998; **45**: 39–41.

Chapter 12

Airway management

Jeremy Collins

12.1 Introduction

For any anesthesiologist there can be few, if any, more alarming clinical situations than a total inability to manage a patient's airway. When this occurs in the MO patient, the rapid development of hypoxemia will exaggerate the critical nature of such an event.

The number of MO patients in society continues to rise exponentially and is matched by an increase in the number of extremely obese patients requiring both hospitalization and intensive care unit admission. The number of bariatric procedures being performed on an annual basis is also rising exponentially. Most anesthesiologists will therefore have frequent interactions with such patients and must practice constant vigilance in managing their airways.

Recent data from the American Society of Anesthesiologists (ASA) Closed Claim Database justifies this concern [1]. Obese patients were involved in 37% of all adverse airway events occurring upon induction, and 58% of those occurring following extubation. A large proportion of these resulted in brain damage or death. Reports of anesthesia-related deaths in obstetric practice point to difficulties with airway management in MO parturients as the primary cause [2].

It is therefore surprising that reviews on the predicted association between obesity and difficult airway management, especially with regard to intubation of the trachea, have not agreed on a well-defined relationship [3, 4].

The aim of this chapter is to apprise the reader of key concepts relating to the principles and practice of airway management in the MO patient. The literature underlying the assumptions about obesity and increased difficulty of airway management will be reviewed. The anatomic and physiologic characteristics of obesity that contribute toward airway management difficulties will be discussed. Management strategies and useful airway adjuncts and techniques will be presented.

12.2 Morbid obesity and difficult airway management – what is the risk?

The ASA Task Force on the management of the difficult airway defines a difficult airway as the "clinical situation in which a conventionally trained anesthesiologist experiences problems with (a) face *mask ventilation* of the upper airway or (b) *tracheal intubation*, or both."[5].

Unlike difficult intubation, difficult face mask ventilation has attracted limited attention, partly because of its rarity and partly because of difficulty defining it. Criteria used to define difficulty have included the ability to maintain oxygen saturation (SaO_2) above 92%, the perceived requirement for two providers, or the inability to mask ventilate at all. When these are used, there is general agreement that increased BMI is an independent predictor for difficult mask ventilation [6]. Other important independent predictors include a history of snoring or obstructive sleep apnea (OSA), presence of facial hair, and older age. Many MO patients snore, and although a formal diagnosis of OSA is only present in 5% [7], it is very likely that as many as 80–90% cases of OSA remain undiagnosed in the community [8]. Many patients within this population therefore have more than one risk factor for difficult or impossible face mask ventilation.

Because MO patients are at increased risk of both difficult face mask ventilation and rapid desaturation, conventional teaching has promoted a strategy of awake intubation when difficult intubation is also anticipated. But can the latter be predicted on the basis of BMI per se?

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

Difficult tracheal intubation has been studied with much greater scrutiny in the MO population. The incidence of difficulty has been reported to be three times as high as compared to lean patients [3], or approximately 13–20% of all intubations in the MO [9, 10], but disagreement still exists [11, 12].

A number of confounding factors have led this disagreement. Difficult intubation is not easy to define, because there are degrees of difficulty, and they may vary between laryngoscopists. Defining failed intubation might seem easier, but there are different thresholds for declaring failure, depending on the laryngoscopist, the urgency of the situation, and who or what else is available.

The view obtained at direct laryngoscopy is used as a surrogate for difficult or failed intubation in many clinical studies, even though they are not synonymous. A tracheal tube may be easy to place despite a poor laryngoscopic view, and even a reasonable view may be associated with difficulty passing a tube.

Such studies generally find the same thing: that certain clinical features are more likely to be present in obese or MO patients in whom laryngoscopy is difficult. High Mallampati score (3 or 4), increased neck circumference, and excessive pre-tracheal adipose tissue have all been shown to increase the risk of difficult laryngoscopy in obese patients [12–14].

Predictive tests derived from such data perform well on the sample from which they were derived, but unfortunately produce low positive predictive values when applied to other populations: because most laryngoscopies are easy, most patients who have such features actually pose no problems. It is therefore difficult to make recommendations regarding a cut-off Mallampati score or gender-specific neck circumference that can be applied to clinical practice [15]. Because such tests are derived from the study of direct laryngoscopy only, their application to other techniques of intubation is not valid. The relevance of such predictive tests may therefore decline as the availability and use of optical and videolaryngoscopes continues to expand.

Clinical studies of intubation on morbidly obese patients very often include a degree of bias, which is difficult to eliminate. Patients predicted to be especially difficult are often excluded from studies when clinical judgment suggests awake fiberoptic intubation as a safer approach [6]. Unfortunately, the study of the difficult airways will always suffer from this limitation due to the provider's responsibility to deliver ethical clinical care before considering the scientific value of the patient's inclusion in a study.

The laryngoscopist cannot be blinded to the body habitus of the patient, and some studies use an "intubation difficulty scale" (IDS) that includes potentially subjective elements [14]. It is worth noting that studies using the IDS have found obesity per se a risk factor for difficult intubation [9, 14], whereas those using a measurement of laryngoscopic view have not [12, 16].

A large proportion of patients recruited for airway studies in morbid obesity are recruited from bariatric surgical populations, which typically exhibit a large preponderance of female patients. Male fat deposition usually exhibits a more visceral and truncal pattern than the peripheral deposition seen in female patients. Higher rates of OSA are seen in men due to a greater accumulation of fat around the airway [17]. Female patients are only at higher risk of OSA with visceral, rather than peripheral accumulation of fat [18]. It is therefore possible that studies of the airway in morbid obesity select greater numbers of patients where the anatomic impact of obesity is reduced.

A lack of a standard intubating position in MO patients is a further cause of confusion. Although the standard sniffing position for tracheal intubation is achieved in non-obese patients by raising the occiput 8–10 cm with a pillow or head rest, obese patients require much greater elevation of their head, neck, and shoulders to produce the same alignment of axes for intubation. Elevating the upper body and head of MO patients in such a way that their sternum and ear are aligned in a horizontal line (head-elevated laryngoscopy position) significantly improves the laryngoscopic view [19]. In studies where the head position is only described as sniffing, this suboptimal position may have resulted in a higher incidence of grade 3 and 4 Cormack–Lehane laryngoscopic views and exaggerated the difficulty. Until a standard intubating position is adopted for research purposes, comparing studies using different positions will continue to confound the issue.

The relationship between difficult airways and morbid obesity remains unclear. It is likely that a small subset of patients with wide necks, OSA and high Mallampati scores will present difficulty with intubation in the elective and emergency settings. All anesthesiologists must proceed with caution in a patient population where difficult oxygenation can be anticipated with more certainty.

12.3 Airway anatomy in morbid obesity

Numerous anatomic factors contribute to difficult airway management in the MO patient. Excess adipose

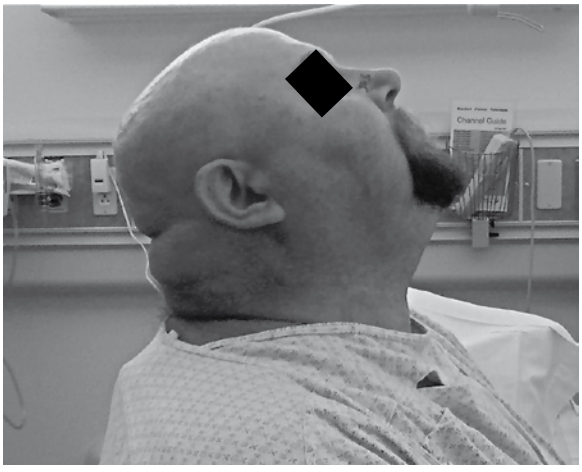


Figure 12.1 Excess deposition of fat in the posterior aspect of the neck restricts craniocervical extension.

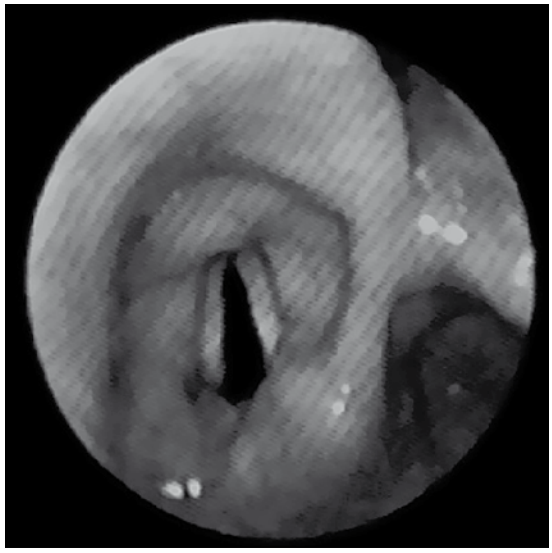
tissue in the face and cheeks interferes with application of a tight-fitting mask. Large breasts in both male and female patients encroach into the submandibular area and restrict access for external laryngeal manipulation, laryngoscope handles, and other intubation devices. Increased deposition of adipose tissue in the anterior neck further restricts access and increases difficulty in palpation of landmarks making surgical access difficult to perform in an emergency.

Fat deposition also occurs at the occiput and posterior aspect of the neck. When severe, this reduces craniocervical mobility and interferes with optimal head positioning for intubation and reduces maximal mouth opening [20] (Figure 12.1).

Craniocervical mobility can also be restricted by deposition of glycosylated collagen in joints that may occur in MO patients who develop diabetes [16, 21].

There is an inverse relationship between pharyngeal area and obesity. Pharyngeal airway size is determined by a balance between the soft tissues through which it is formed and the bony craniofacial skeleton that supports it. Although patency is maintained by fine neural control of pharyngeal dilator muscles, a greater tendency to collapse exists when the mass of soft tissue increases. This explains the strong correlation of morbid obesity with OSA. MRI shows deposition of adipose tissue into nearly all pharyngeal structures: the uvula, the tonsils, the tonsillar pillars, the tongue, aryepiglottic folds, and most predominantly, the lateral pharyngeal walls. Deposition of such adipose tissue can change the normal appearance at laryngoscopy so much that it may be hard to recognize the glottic opening (Figure 12.2a and 12.2b).

(a)



(b)

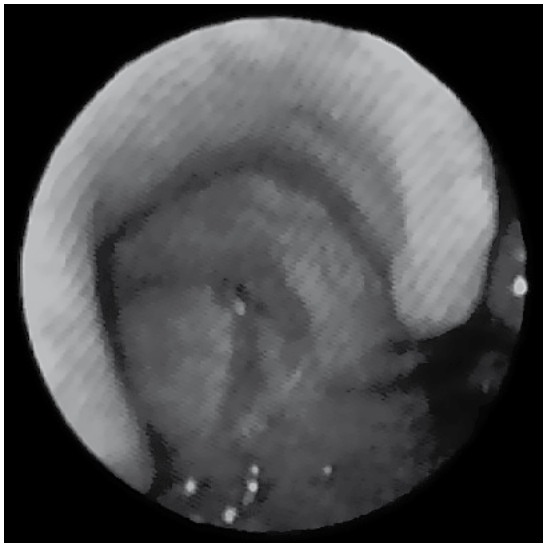


Figure 12.2 (a-b) Still captures from videolaryngoscopy of two morbidly obese patients. In (a) the base of the epiglottis (pediole) appears enlarged by fat deposition. This can also occur to such a degree in the false vocal cords that the glottic opening appears closed and difficult to recognize, even when the vocal cords are in the abducted position, as in (b).

Airway narrowing from depositions of fat in the lateral walls of the pharynx can be further exaggerated by external compression from superficial depositions of fat in the neck, as seen in male-pattern obesity.

Neurally mediated preservation of airway patency is maintained during wakefulness, but is reduced during sleep and sedation and is abolished during paralysis. Mechanical interventions for opening the upper airway are therefore mandatory in

these patients during anesthesia care. Mandibular advancement, head extension, and the sniffing position enlarge the craniofacial size, thereby improving the upper airway size. A sitting, lateral, or reversed Trendelenburg position reduces the gravitational impact of the excessive soft tissue volume on pharyngeal airway lumen, also improving the anatomic balance toward patency.

Responses to mechanical interventions in obese persons seem to differ from those in non-obese persons. Mandibular advancement does not increase the retropalatal (nasopharyngeal) cross-sectional area in obese persons, as it does in lean subjects because of the lateral deposition of fat tissue in the pharynx [22]. In contrast, the retroglossal (oropharyngeal) airway does improve with mandibular advancement in the obese, indicating an advantage of positive-pressure ventilation through an oral airway during anesthesia induction. An increase in lung volume also improves the anatomic balance in the pharyngeal airway, possibly due to increasing longitudinal traction forces on the upper airway soft tissue [23]. The beneficial effect of an increase in lung volume is greater at the retropalatal airway of obese OSA patients than non-obese OSA patients.

12.4 Pathophysiologic changes in morbid obesity affecting airway management

12.4.1 Gastroesophageal considerations

Obesity may in some way promote the development of gastroesophageal reflux disease. Many consider MO patients at risk for gastric aspiration based on assumptions regarding gastric volumes, barrier pressure, and gastric pH. Standard teaching therefore advocates either awake intubation or rapid sequence induction with cricoid pressure.

However, MO alone is an unproven risk factor for pulmonary aspiration during induction of anesthesia on the basis of residual gastric volume [24]. Gastric capacity is increased in the obese, but is compensated by faster gastric emptying times. Obese fasted patients are not more likely than lean patients to have high volumes of acidic gastric contents [25], or higher barrier pressures [26]. Even in patients demonstrating increased barrier pressures, there is no direct relationship between these pressure gradients and abnormal acid exposure in the esophagus, suggesting a multifactorial mechanism to the disease [27]. One exception is patients who present for surgery following gastric banding. They present an increased risk for aspiration due to high pre-operative residual gastric volumes [28].

One technique to lessen the chance for pulmonary aspiration is to compress the esophagus against the vertebral bodies by applying cricoid pressure. In an observational study using MRI, the cricopharyngeal muscle rather than the esophagus was lying posterior to the cricoid in the majority of subjects [29]. During cricoid pressure, the esophagus was displaced laterally in 90% of the subjects, and the airway was displaced in 67%, and narrowed in 81% of the subjects. Considering that the esophagus proper is usually 10 mm below the cricoid and often displaced laterally, the protection afforded by compression is questionable. Cricoid pressure has not been proven to prevent aspiration.

In elective, fasted, morbidly obese patients with no other risk factors, the need for rapid-sequence induction with cricoid pressure due to a presumed risk for regurgitation and aspiration is debatable.

12.4.2 Pulmonary considerations

Obesity results in a restrictive lung pattern due to both increased pulmonary blood volume and increased chest wall mass from adipose tissue. Abnormal diaphragm position, upper airway resistance, and increased daily CO_2 production exacerbate respiratory load and further increase the work of breathing. The consequences of this restrictive pattern are decreased functional residual capacity, vital capacity, total lung capacity, inspiratory capacity, minute ventilatory volume, and expiratory reserve volume. Patients may also exhibit an obesity-related obstructive air flow pathology that manifests itself as an increased ratio of forced expiratory volume in 1 sec to forced vital capacity (FEV_1:FVC).

These changes are exacerbated following induction of anesthesia. A 50% reduction in functional residual capacity (FRC) occurs in obese patients upon induction of anesthesia compared to a 20% fall in non-obese subjects. The resultant intra-pulmonary shunt is as high as 10–25% in obese patients compared to 2–5% in lean patients. This reduced oxygen reservoir, combined with the high metabolic rate in obesity, results in rapid desaturation. It is therefore most important to provide effective preoxygenation with a well-sealed circuit, for a long enough period (over 3 min) to ensure filling of the alveolar, arterial, venous, and tissue spaces [30].

Anesthetic induction with the head and chest raised above the horizontal can partially offset the fall in FRC and prolong the time before desaturation occurs [31]. The addition of moderate continuous positive airways pressure (CPAP), can improve oxygenation and limit atelactasis [32].

The above changes in pulmonary function, notably increased work of breathing and large intrapulmonary shunt result in severe hypoxia if the MO patient is allowed to breath spontaneously following induction of anesthesia. Airway management must therefore be directed toward providing a means of positive pressure ventilation via a cuffed tracheal tube as the primary strategy.

The remainder of the chapter will present options for airways management in an order that reflects their application in the ASA Difficult Airway Algorithm [5].

Desaturation occurs rapidly following induction of anesthesia. Since MO patients may present difficulties with oxygenation, planned strategies should achieve control of the airway quickly. Repeated attempts should be minimized to avoid further problems with oxygenation secondary to trauma.

12.5 Intubation strategies for awake intubation

In the presence of a known full stomach or when preoperative evaluation leads the practitioner to suspect very difficult intubation or difficult supraglottic oxygenation, awake intubation may be the preferred option. A previous history of failed ventilation or intubation may also indicate a more cautious approach.

Awake intubation will maintain airway patency and spontaneous respiration, but is not without hazard in this difficult patient group [1]. Great care should be taken with sedative drugs as airways obstruction may occur with minimal sedation, especially in the subgroup of patients with OSA. Application of local anesthesia to the vocal cords and infraglottic structures supposedly does not increase the risk of aspiration from full stomach, provided that the patient does not become over sedated [33].

The procedure must be done well. If distress occurs, patients may refuse awake intubation in future surgeries. Careful titration of the ultra-short acting remifentanil can provide smooth conditions for awake intubation in difficult cases [34]. The selective alpha-2 adrenergic agonist dexmedetomine has also recently been reported to provide satisfactory conditions for awake intubation in MO patients [35].

12.5.1 Flexible fiberoptic laryngoscopy

Flexible fiberoptic laryngoscopy is the most common technique chosen for awake intubation, but visualization may be difficult when excess fat deposition results in airway narrowing and redundant folds of tissue. Instructing the patient to both protrude the tongue and phonate can improve the diameter of the airway and aid visualization. Upright posture of the upper body utilizes the effect of gravity and may also increase the pharyngeal space. Use of the nasal rather than the oral route may provide a straighter passage of the fiberscope, but may risk epistaxis if adequate vasoconstriction of the nasal mucosa is not achieved. Additional oxygen can be delivered through the working channel of the flexible scope at 1–2 l min^{-1}. Care should be taken if the distal tip of the flexible scope goes beyond the carina as barotrauma can result following oxygen insufflation. The pharyngeal airway may be splinted open during nasal fiberoptic intubation by application of nasal CPAP on the contra lateral nostril [36].

If technical difficulties arise with flexible fiberoptic laryngoscopy, a laryngeal mask airway (LMA North America, Inc) (LMA) can be used as a conduit. The airway tube of the LMA holds the surrounding soft tissues open and permits a technically easier passage of the fiberscope. Numerous case reports of difficult airways describe the insertion of Classic LMA in the awake patient following application of topical anesthesia in the mouth [37]. Superior laryngeal nerve blocks and trans-tracheal injection of local anesthetic via the cricothyroid membrane improve patient comfort. Passage and inflation of the cuff can be uncomfortable, but asking the patient to swallow the device can aid insertion. Once in position, it is well tolerated, although recurrent swallowing and salivation are common. As well as functioning as a conduit for fiberoptic intubation, the LMA provides a valuable airway and means of delivering high concentrations of oxygen. A recent case report describes the awake insertion of a Proseal LMA in a 980 lb patient followed by anesthetic induction and fiberoptic intubation. The Proseal LMA was used to deliver positive pressure ventilation throughout the intubation with no significant periods of hypoxemia [38].

12.5.2 Fastrach LMA

Use of the intubating (Fastrach®) LMA is also well described in awake MO patients [39]. It is associated

with high success rates, even when the tracheal tube is passed blindly and achieves intubation in a shorter time when compared with flexible fiberoptic intubation via an Ovassapian airway [40].

A more recent approach has superseded this latter technique by using the C-trach LMA®, which permits visualization of the glottic opening as well as oxygenation [41] (Figure 12.3).

The authors describe a technique in which anesthesia is induced once successful visualization of the vocal cords has been achieved on the monitor. Even with experience however, this occurs only 50% of the time without requiring further manipulation. As the glottis remains in view, inhalational anesthesia is induced and the tracheal tube passed without paralysis, removing any requirement to topicalize the infraglottic structures or cease spontaneous/assisted respiration.

Figure 12.3 C-trach LMA. The monitor can be attached to the airway tube either before or following insertion of the LMA. A small camera behind the epiglottic elevator allows visualization of the glottis.

12.6 Intubation strategies following induction of anesthesia

Adequate preparation of the MO patient for induction of anesthesia must be focused on the requirement for both optimal preoxygenation and optimal conditions for tracheal intubation. If difficulty occurs, a secondary plan should provide a rapid availability of additional airway equipment and skilled assistance.

The presence of facial hair is the only modifiable risk factor for difficult intubation and may interfere with effective taping of tracheal tubes following intubation. It is therefore appropriate to request patients remove beards pre-operatively if any difficulty is predicted.

Preoxygenation should occur through a well-seated face mask for 3 min of tidal respirations rather than the fast track technique of three vital capacity breaths [30].

Positioning the patient properly is vitally important. Elevation of the chest above the abdomen during preoxygenation will increase the time period before desaturation occurs if difficulties arise with ventilation and intubation. This position will facilitate mask ventilation by offsetting the mass loading of the abdominal and chest walls, reducing the restrictive lung defect and increasing lung compliance. Increasing lung volumes may improve airway patency.

An optimal view during direct laryngoscopy occurs when there is good alignment of the oral, pharyngeal and laryngeal axes. Debate exists as to whether the standard sniffing position achieves this in normal patients, but its superiority in obese patients is not contested [42]. However, a "standard" sniffing position in MO patients demands increased elevation of the shoulders, neck and head into a head-elevated laryngoscopy position (HELP) [43]. This position increases laryngeal exposure during direct laryngoscopy when compared to a simple headrest underneath the occiput [19]. It also provides an optimal position for mask ventilation [44], increases the submandibular space for laryngoscopy handles and other airway techniques such as videolaryngoscopy and improves surgical exposure for invasive oxygenation.

Various methods for achieving this position have been described, including manipulation of the operating table, blankets, inflatable pillows, inflatable ramps, and wedge-shaped foam pillows [19, 45–47] (Figure 12.4a–d).

No single method is superior [48], but a simple confirmation of horizontal alignment of the ear with the sternum provides a useful way to check optimal positioning in the operating room.

In the fasted MO patient with no other risk factors for aspiration, recent reviews suggest rapid sequence induction with cricoid pressure is unnecessary. However, the choice and dose of muscle relaxant should achieve optimal intubating conditions within the shortest time possible. Succinylcholine dosed by actual body weight is preferred [49].

12.6.1 Primary strategy: Direct laryngoscopy

Assuming optimal positioning, the standard Macintosh or Miller laryngoscopes are the method of first choice.

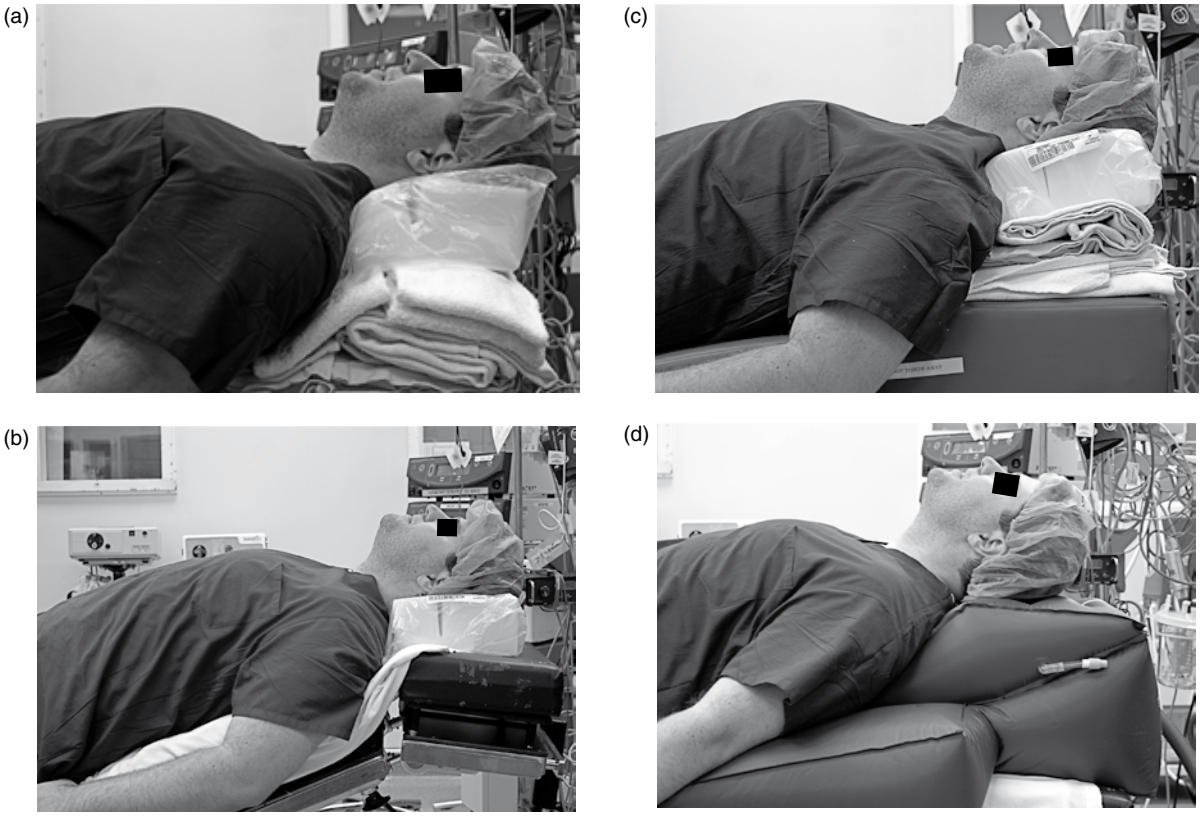


Figure 12.4 Four different methods for achieving the head-elevated laryngoscopy position are shown. (a) Shea™ head rest with additional blankets. (b) Adjustment of the OR table by flexion at the thigh-trunk hinge to elevate the chest and abdomen with extension at the trunk-neck hinge. (c) Wedge-shaped Troop™ pillow (Mercury Medical). (d) Inflatable "Rapid Airway Management Positioner" (RAMP™) (Airpal). A horizontal line can be drawn between the sternum and ear in the four methods of positioning shown.

These instruments are familiar, inexpensive, readily available throughout all hospitals, and easy to maintain in good working order. Excellent laryngeal exposure can be expected in most patients, allowing easy and rapid tracheal intubation. When a Cormack–Lehane grade 3 view is seen, a bougie (single use, multi-use: Eschmann™, or Frova™) can provide an invaluable adjunct to direct laryngoscopy, and avoids repeated blind attempts with a styletted tracheal tube.

12.6.2 Secondary strategy: Alternative intubation devices

If intubation is not successful after one or two attempts at direct laryngoscopy, further efforts should be directed toward maintaining oxygenation and using an alternative technique.

12.6.2.1 Trachlight® (Laerdel Medical, Canada)

Lighted stylets (e.g., Trachlight) have a poor success rate in the MO due to reduced transillumination of light through excess fat tissue, and cannot be recommended [50].

12.6.2.2 Flexible fiberoptic laryngoscopes

Flexible fiberoptic laryngoscopy in the anesthetized patient will be more difficult than when awake because of a reduced pharyngeal space. Intubation takes longer than other techniques, and time available will be restricted by the patient's intolerance to apnea. In the setting of failed direct laryngoscopy, its use should only be considered by expert endoscopists. However, intubation through a Classic LMA using a flexible fiberoptic scope has been reported numerous times with success rates approaching 100%.

12.6.2.3 Rigid fiberoptic laryngoscopes

Incorporation of fiberoptic technology into rigid instruments for airway management is not new. The Bullard laryngoscope® has gained more popularity than other rigid scopes such as the Wu Scope®,

Augustine Scope® and Upsherscope®. Although isolated case reports of their successful use in difficult airways exist, their penetration remains limited and many anesthesiologists have never used them. The author has used the Video Macintosh System® (Karl Storz Endoscopy, America Inc) in one study on MO patients [19]. No new skill is necessary since it is essentially a Macintosh blade. The laryngeal exposure seen on the monitor is usually superior to the direct laryngoscopic view. Similar findings have been observed using a Rusch X-Lite Videolaryngoscope [51](Rusch Medical, Germany). However, the improved views in this study did not lead to faster intubation times. Expense, lack of portability, and difficult maintenance contribute to the limited uptake of these devices by the anesthetic community.

12.6.2.4 Video and optical laryngoscopy

The last 5 years has seen an exponential rise in the numbers of these devices available. Modern technology now provides good quality images of the airway projected from either a lens or video camera in the distal portion of the blade. These devices share an anatomic advantage over direct laryngoscopy by allowing the operator to see around a greater curve than the Macintosh blade provides, albeit indirectly. An anatomic inability to align the laryngeal, oral, and pharyngeal axes no longer imposes the restriction to laryngeal exposure that is seen with direct laryngoscopy (Figure 12.5).

Human and manikin studies to date confirm that these devices produce greater visualization of the vocal cords using less force. But despite an improved view, the insertion of the tracheal tube may be more difficult and take more time when compared with a Macintosh blade [52].

The view on the monitor reveals only the laryngeal inlet – the tip of the tracheal tube is often passed blindly into the field of view. Advancement of the tracheal tube may require a customized introducer or a built-in guiding channel. This can make the device bulky and the technique more complicated than conventional laryngoscopy, with a requirement for learning and practice. New skills must be learned.

No single device has emerged as superior in the MO patient. Speed of intubation must remain a high priority in this population. The following summary of different devices emphasizes those in which published data exists for use in MO, and is not intended as a thorough explanation of technique.

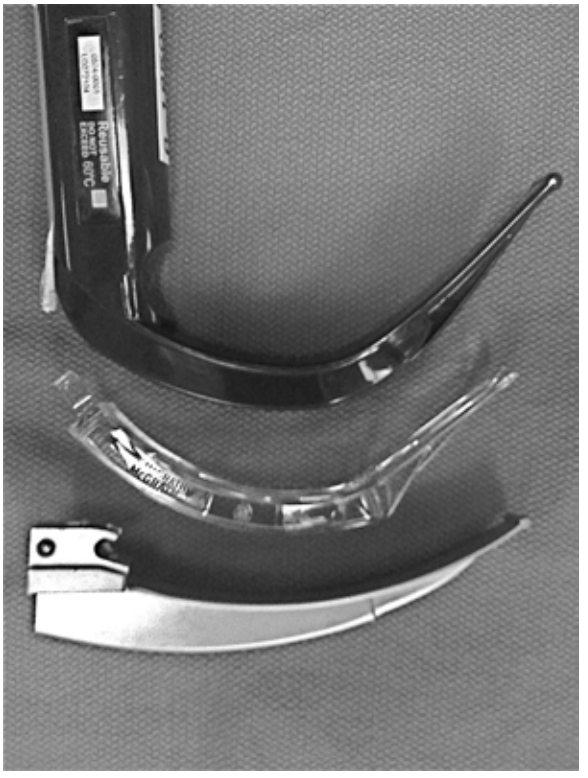


Figure 12.5 Distal blades of two modern videolaryngoscopes compared to a standard Macintosh 3 blade. Note the greater angulation of both the Glidescope (upper) and McGrath blades (middle) compared to the Macintosh blade (lower). This allows more anterior laryngeal exposure.

12.6.2.5 Glidescope® (Verathon Inc, USA)

The short handle may assist in placement into the mouth, especially in patients with a short neck. An alternative design (Ranger®) offers a compact, portable version without sacrificing utility. Even when views are excellent, manipulation of the tube into the trachea can take longer when compared with direct laryngoscopy [53]. Several case reports describe upper airway injuries caused by blind advancement of the styletted tube before it reaches the area viewed on the monitor [54]. An early report of use in 30 MO patients reveals 2 patients where laryngeal exposure was poor, one of which required an alternative technique [55].

12.6.2.6 McGrath® Videolaryngoscope (LMA North America Inc)

It has a similar shaped blade as the Glidescope, which also necessitates blind advancement of tube until it can be viewed on the monitor. The compact design with a small monitor attached to the handle make it easily portable. Its novel design allows rapid adjustment of

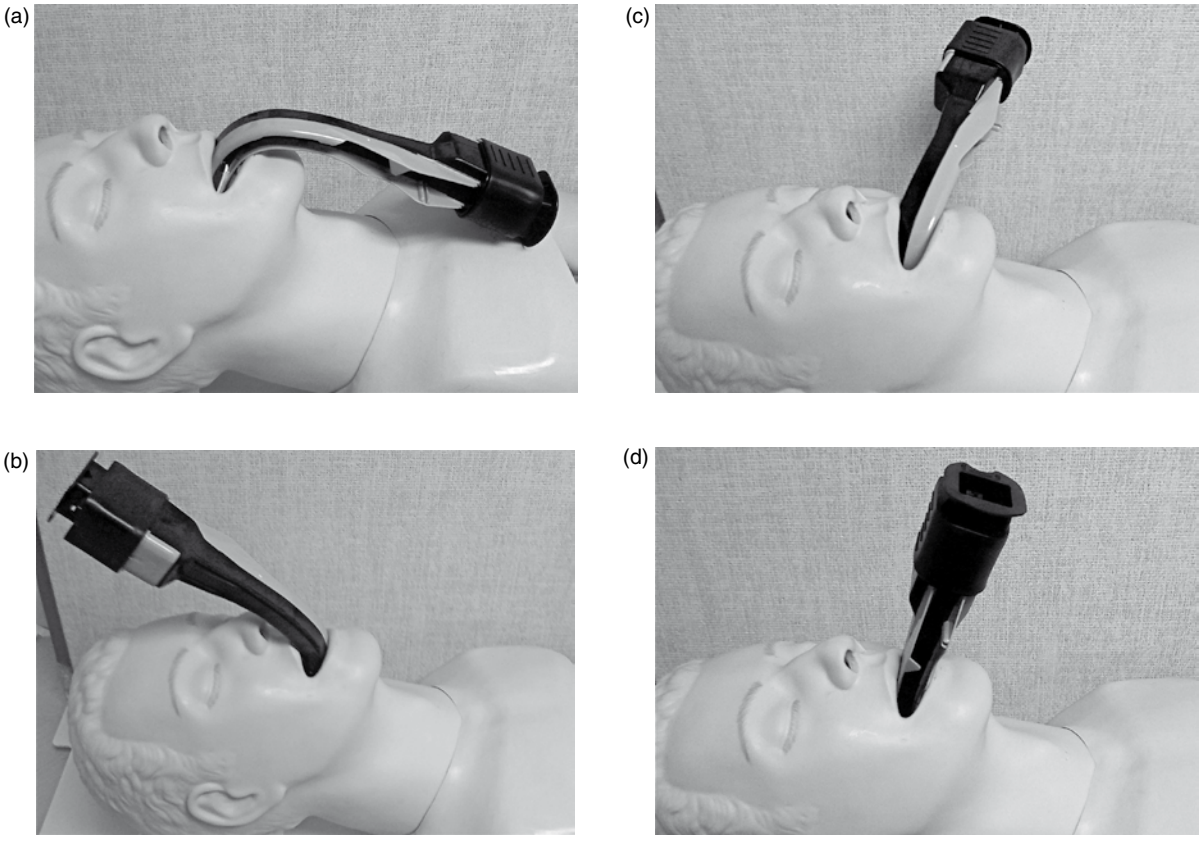


Figure 12.6 (a–d) Airtraq® insertion in morbid obesity can be difficult when the proximal viewer hits the anterior chest (a). This can be overcome by reverse insertion (b) or lateral insertion (c) followed by clockwise rotation into the correct position (d). The device is 2.8 cm wide and therefore requires adequate mouth opening to achieve this.

blade length if necessary. If insertion into the mouth is restricted in obese patients due to contact of the handle with the chest, then the blade can be disengaged, inserted into the mouth, and the handle reattached.

12.6.2.7 Airtraq® (Prodol Meditec S.A)

The Airtraq® is a single-use optical laryngoscope, which incorporates a guiding channel for atraumatic advancement of the tracheal tube. Its properties include anatomic shape and a built-in anti-fog mechanism, and it requires no maintenance. It can be used immediately when needed as back-up in failed direct laryngoscopy. Difficulty with insertion in MO patients with short chin–sternum distance occurs in 20% of cases, but can be overcome by a rotational maneuver through 90–180° (analogous to insertion of an oropharyngeal airway) (Figures 12.6a–d).

It has been used for successful intubation following failed direct laryngoscopy in a morbidly obese parturient [56], and produces faster intubation times in MO patients when compared with Macintosh direct laryngoscopy [57].

12.6.2.8 Pentax–AWS® (Pentax Corporation, Japan)

This device is designed for multiple-use. It has a distal blade similar in design to Airtraq® resulting in the same technique of intubation. The tracheal tube also advances through a built-in channel. The proximal portion incorporates a large screen producing a high-fidelity color video image, but results in bulkier design compared to Airtraq. The distal blade is single use, and difficult insertion into mouth in MO patients can be overcome by insertion of the distal blade alone, followed by attachment of the proximal video portion [58].

12.6.2.9 Intubating (Fastrach™) LMA and C-Trach

The Fastrach LMA is well established in the ASA Difficult Airway Algorithm, both in elective and emergency settings. Clinical studies suggest a failure

rate of 3–4% in morbid obesity, which may be comparable to the failure rate with direct laryngoscopy in this patient population [59, 60]. Even in those patients where blind passage of the tracheal tube is not possible, the Fastrach LMA allows adequate ventilation, even in inexperienced hands. Deposition of fat in lateral pharyngeal walls may cause railroading of the device into a better position in the obese when compared to lean patients. When a flexible fiberscope is used to assist intubation through the device, failure is eliminated.

The addition of video capability to the Fastrach LMA promotes it to a C-Trach™ LMA. Following insertion in morbidly obese patients, 50% require further manipulation of the device to produce visualization. This results in longer intubation times compared to direct laryngoscopy, but with less desaturation as ventilation is easily achieved throughout [61]. Intubation is 100% successful with the C-Trach.

12.7 Suggested strategy for intubation of morbidly obese patients

Based on the available literature to date, an initial intubation plan by direct laryngoscopy can be justified. If the trachea is not intubated and failure occurs, and in the absence of difficulty with ventilation, then an Airtraq® provides high success rates in the fastest times. If difficulties arise with ventilation, then either Ctrach or Fastrach will provide better ventilation with a high chance of intubation. The above assumes familiarity and practice with all these devices.

12.7.1 Rescue oxygenation in failed intubation and failed ventilation

When possible, attempts should be made to awaken the patient, and assistance should be sought. In order to maintain SaO_2 in MO patients, continued ventilation would be necessary before the return of spontaneous ventilation occurs.

12.7.1.1 Non-invasive

The Proseal LMA™ provides effective ventilation in MO patients, and is a useful temporary measure [62]. Most importantly in the setting of an unprotected airway, access to the stomach is possible via the drainage tube. Higher seal pressures are likely when compared to LMA Classic, which may be required to achieve adequate ventilation. Intubation through the Proseal LMA may be possible with the subsequent use of a flexible scope.

12.7.1.2 Combitube™ (Tyco-Kendall, Mansfield, MA, USA)

Several case reports confirm the place of the Combitube in the failed airway in morbid obesity [63]. The device enters the upper esophagus in 95% of the time. Fiberoptic laryngoscopy through the device is only possible if it enters the trachea. The Combitube can provide invaluable oxygenation until a more definitive surgical airway is secured.

12.7.2 Invasive techniques

The utility of invasive techniques may be limited by fat deposition such that surgical landmarks will be obscured. Limited neck extension will also restrict surgical access in some patients. Small catheter techniques at the cricothyroid membrane may not provide sufficient caliber to effectively ventilate a morbidly obese patient. The reader is referred to surgical texts for descriptions of tracheostomy techniques in morbid obesity.

12.8 Conclusion

Although the MO patient may present a great challenge to the anesthesiologist managing their airway, careful planning and preparation will usually avoid any untoward events. Bedside tests remain poor at predicting difficulty. Practitioners should become familiar with the newer devices that can facilitate easier intubation and ventilation when the primary strategy fails. Equal care and equipment should be available for extubation as well as intubation.

References

1. Peterson GN, Domino KB, Caplan RA, Posner KL, Lee LA, Cheney FW. Management of the difficult airway: a closed claims analysis. *Anesthesiology* 2005; **103**: 33–9.
2. Cooper GM, McClure JH. Anaesthesia chapter from Saving mothers' lives; reviewing maternal deaths to make pregnancy safer. *Br J Anaesth* 2008; **100**: 17–22.
3. Shiga T, Wajima Z, Inoue T, Sakamoto A. Predicting difficult intubation in apparently normal patients: a meta-analysis of bedside screening test performance. *Anesthesiology* 2005; **103**: 429–37.
4. Collins JS, Lemmens HJ, Brodsky JB. Obesity and difficult intubation: where is the evidence? *Anesthesiology* 2006; **104**: 617; author reply 8–9.
5. Practice guidelines for management of the difficult airway: an updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *Anesthesiology* 2003; **98**: 1269–77.

6. Kheterpal S, Han R, Tremper KK, Shanks A, Tait AR, O ' Reilly M, *et al*. Incidence and predictors of difficult and impossible mask ventilation. *Anesthesiology* 2006; **105**: 885–91.
7. Adams JP, Murphy PG. Obesity in anaesthesia and intensive care. *Br J Anaesth* 2000; **85**: 91–108.
8. Young T, Evans L, Finn L, Palta M. Estimation of the clinically diagnosed proportion of sleep apnea syndrome in middle-aged men and women. *Sleep* 1997; **20**: 705–6.
9. Juvin P, Lavaut E, Dupont H, Lefevre P, Demetriou M, Dumoulin JL, *et al*. Difficult tracheal intubation is more common in obese than in lean patients. *Anesth Analg* 2003; **97**: 595–600.
10. Voyagis GS, Kyriakis KP, Dimitriou V, Vrettou I. Value of oropharyngeal Mallampati classification in predicting difficult laryngoscopy among obese patients. *Eur J Anaesthesiol* 1998; **15**: 330–4.
11. Ezri T, Medalion B, Weisenberg M, Szmuk P, Warters RD, Charuzi I. Increased body mass index per se is not a predictor of difficult laryngoscopy. *Can J Anaesth* 2003; **50**: 179–83.
12. Brodsky JB, Lemmens HJ, Brock-Utne JG, Vierra M, Saidman LJ. Morbid obesity and tracheal intubation. *Anesth Analg* 2002; **94**: 732–6.
13. Ezri T, Gewurtz G, Sessler DI, Medalion B, Szmuk P, Hagberg C, *et al*. Prediction of difficult laryngoscopy in obese patients by ultrasound quantification of anterior neck soft tissue. *Anaesthesia* 2003; **58**: 1111–4.
14. Gonzalez H, Minville V, Delanoue K, Mazerolles M, Concina D, Fourcade O. The importance of increased neck circumference to intubation difficulties in obese patients. *Anesth Analg* 2008; **106**: 1132–6.
15. Hassani A, Kessell G. Neck circumference and difficult intubation. *Anesth Analg* 2008; **107**: 1756–7; author reply 7.
16. Mashour GA, Kheterpal S, Vanaharam V, Shanks A, Wang LY, Sandberg WS, *et al*. The extended Mallampati score and a diagnosis of diabetes mellitus are predictors of difficult laryngoscopy in the morbidly obese. *Anesth Analg* 2008; **107**: 1919–23.
17. Benumof JL. Obesity, sleep apnea, the airway and anesthesia. *Curr Opin Anaesthesiol* 2004; **17**: 21–30.
18. Busetto L, Calo E, Mazza M, De Stefano F, Costa G, Negrin V, *et al*. Upper airway size is related to obesity and body fat distribution in women. *Eur Arch Otorhinolaryngol* 2009; **266**: 559–63.
19. Collins JS, Lemmens HJ, Brodsky JB, Brock-Utne JG, Levitan RM. Laryngoscopy and morbid obesity: a comparison of the "sniff" and "ramped" positions. *Obes Surg* 2004; **14**: 1171–5.
20. Calder I, Picard J, Chapman M, O ' Sullivan C, Crockard HA. Mouth opening: a new angle. *Anesthesiology* 2003; **99**: 799–801.
21. Erden V, Basaranoglu G, Delatioglu H, Hamzaoglu NS. Relationship of difficult laryngoscopy to long-term non-insulin-dependent diabetes and hand abnormality detected using the 'prayer sign'. *Br J Anaesth* 2003; **91**: 159–60.
22. Isono S, Tanaka A, Tagaito Y, Sho Y, Nishino T. Pharyngeal patency in response to advancement of the mandible in obese anesthetized persons. *Anesthesiology* 1997; **87**: 1055–62.
23. Tagaito Y, Isono S, Remmers JE, Tanaka A, Nishino T. Lung volume and collapsibility of the passive pharynx in patients with sleep-disordered breathing. *J Appl Physiol* 2007; **103**: 1379–85.
24. Maltby JR, Pytka S, Watson NC, Cowan RA, Fick GH. Drinking 300 ml of clear fluid two hours before surgery has no effect on gastric fluid volume and pH in fasting and non-fasting obese patients. *Can J Anaesth* 2004; **51**: 111–5.
25. Harter RL, Kelly WB, Kramer MG, Perez CE, Dzwonczyk RR. A comparison of the volume and pH of gastric contents of obese and lean surgical patients. *Anesth Analg* 1998; **86**: 147–52.
26. Zacchi P, Mearin F, Humbert P, Formiguera X, Malagelada JR. Effect of obesity on gastroesophageal resistance to flow in man. *Dig Dis Sci* 1991; **36**: 1473–80.
27. Pandolfino JE. The relationship between obesity and GERD: "big or overblown". *Am J Gastroenterol* 2008; **103**: 1355–7.
28. Jean J, Compere V, Fourdrinier V, Marguerite C, Auquit-Auckbur I, Milliez PY, *et al*. The risk of pulmonary aspiration in patients after weight loss due to bariatric surgery. *Anesth Analg* 2008; **107**: 1257–9.
29. Smith KJ, Dobranowski J, Yip G, Dauphin A, Choi PT. Cricoid pressure displaces the esophagus: an observational study using magnetic resonance imaging. *Anesthesiology* 2003; **99**: 60–4.
30. Benumof JL. Preoxygenation: best method for both efficacy and efficiency. *Anesthesiology* 1999; **91**: 603–5.
31. Dixon BJ, Dixon JB, Carden JR, Burn AJ, Schachter LM, Playfair JM, *et al*. Preoxygenation is more effective in the 25 degrees head-up position than in the supine position in severely obese patients: a randomized controlled study. *Anesthesiology* 2005; **102**: 1110–5; discussion 5A.
32. Coussa M, Proietti S, Schnyder P, Frascarolo P, Suter M, Spahn DR, *et al*. Prevention of atelectasis formation during the induction of general anesthesia in morbidly obese patients. *Anesth Analg* 2004; **98**: 1491–5.
33. Ovassapian A, Krejcie TC, Yelich SJ, Dykes MH. Awake fibreoptic intubation in the patient at high risk of aspiration. *Br J Anaesth* 1989; **62**: 13–6.
34. Puchner W, Obwegeser J, Puhringer FK. Use of remifentanil for awake fiberoptic intubation in a

morbidly obese patient with severe inflammation of the neck. *Acta Anaesthesiol Scand* 2002; **46**: 473–6.

35. Nagashima M, Kunisawa T, Takahata O, Iwasaki H. [Dexmedetomidine infusion for sedation during awake intubation]. *Masui* 2008; **57**: 731–4. [in Japanese]
36. Rothfleisch R, Davis LL, Kuebel DA, deBoisblanc BP. Facilitation of fiberoptic nasotracheal intubation in a morbidly obese patient by simultaneous use of nasal CPAP. *Chest* 1994; **106**: 287–8.
37. Godley M, Reddy AR. Use of LMA for awake intubation for caesarean section. *Can J Anaesth* 1996; **43**: 299–302.
38. Doyle DJ, Zura A, Ramachandran M, Lin J, Cywinski JB, Parker B, *et al*. Airway management in a 980-lb patient: use of the Aintree intubation catheter *J Clin Anesth* 2007; **19**: 367–9.
39. Brimacombe JR. Difficult airway management with the intubating laryngeal mask. *Anesth Analg* 1997; **85**: 1173–5.
40. Dhar P, Osborn I, Brimacombe J, Meenan M, Linton P. Blind orotracheal intubation with the intubating laryngeal mask versus fibreoptic guided orotracheal intubation with the Ovassapian airway. A pilot study of awake patients. *Anaesth Intensive Care* 2001; **29**: 252–4.
41. Wender R, Goldman AJ. Awake insertion of the fibreoptic intubating LMA CTrach in three morbidly obese patients with potentially difficult airways. *Anaesthesia* 2007; **62**: 948–51.
42. Adnet F, Baillard C, Borron SW, Denantes C, Lefebvre L, Galinski M, *et al*. Randomized study comparing the "sniffing position" with simple head extension for laryngoscopic view in elective surgery patients. *Anesthesiology* 2001; **95**: 836–41.
43. Levitan RM, Mechem CC, Ochroch EA, Shofer FS, Hollander JE. Head-elevated laryngoscopy position: improving laryngeal exposure during laryngoscopy by increasing head elevation. *Ann Emerg Med* 2003; **41**: 322–30.
44. Isono S. One hand, two hands, or no hands for maximizing airway maneuvers? *Anesthesiology* 2008; **109**: 576–7.
45. Nissen MD, Gayes JM. An inflatable, multichambered upper body support for the placement of the obese patient in the head-elevated laryngoscopy position. *Anesth Analg* 2007; **104**: 1305–6.
46. Rich JM. Use of an elevation pillow to produce the head-elevated laryngoscopy position for airway management in morbidly obese and large-framed patients. *Anesth Analg* 2004; **98**: 264–5.
47. Zvara DA, Calicott RW, Whelan DM. Positioning for intubation in morbidly obese patients. *Anesth Analg* 2006; **102**: 1592.
48. Rao SL, Kunselman AR, Schuler HG, DesHarnais S. Laryngoscopy and tracheal intubation in the head-elevated position in obese patients: a randomized, controlled, equivalence trial. *Anesth Analg* 2008; **107**: 1912–8.
49. Brodsky JB, Foster PE. Succinylcholine and morbid obesity. *Obes Surg* 2003; **13**: 138–9.
50. Agro F, Hung OR, Cataldo R, Carassiti M, Gherardi S. Lightwand intubation using the Trachlight: a brief review of current knowledge. *Can J Anaesth* 2001; **48**: 592–9.
51. Marrel J, Blanc C, Frascarolo P, Magnusson L. Videolaryngoscopy improves intubation condition in morbidly obese patients. *Eur J Anaesthesiol* 2007; **24**: 1045–9.
52. Malik MA, Maharaj CH, Harte BH, Laffey JG. Comparison of Macintosh, Truview EVO2, Glidescope, and Airwayscope laryngoscope use in patients with cervical spine immobilization. *Br J Anaesth* 2008; **101**: 723–30.
53. Sun DA, Warriner CB, Parsons DG, Klein R, Umedaly HS, Moult M. The GlideScope Video Laryngoscope: randomized clinical trial in 200 patients. *Br J Anaesth* 2005; **94**: 381–4.
54. Cooper RM. Complications associated with the use of the GlideScope videolaryngoscope. *Can J Anaesth* 2007; **54**: 54–7.
55. Cooper RM, Pacey JA, Bishop MJ, McCluskey SA. Early clinical experience with a new videolaryngoscope (GlideScope) in 728 patients. *Can J Anaesth* 2005; **52**: 191–8.
56. Dhonneur G, Ndoko S, Amathieu R, Housseini LE, Poncelet C, Tual L. Tracheal intubation using the Airtraq in morbid obese patients undergoing emergency cesarean delivery. *Anesthesiology* 2007; **106**: 629–30.
57. Ndoko SK, Amathieu R, Tual L, Polliand C, Kamoun W, El Housseini L, *et al*. Tracheal intubation of morbidly obese patients: a randomized trial comparing performance of Macintosh and Airtraq laryngoscopes. *Br J Anaesth* 2008; **100**: 263–8.
58. Suzuki A, Terao M, Fujita S, Henderson JJ. Tips for intubation with the Pentax-AWS Rigid Indirect Laryngoscope in morbidly obese patients. *Anaesthesia* 2008; **63**: 442–4.
59. Combes X, Sauvat S, Leroux B, Dumerat M, Sherrer E, Motamed C, *et al*. Intubating laryngeal mask airway in morbidly obese and lean patients: a comparative study. *Anesthesiology* 2005; **102**: 1106–9; discussion 5A.
60. Frappier J, Guenoun T, Journois D, Philippe H, Aka E, Cadi P, *et al*. Airway management using the intubating laryngeal mask airway for the morbidly obese patient. *Anesth Analg* 2003; **96**: 1510–5.
61. Dhonneur G, Ndoko SK, Yavchitz A, Foucrier A, Fessenmeyer C, Pollian C, *et al*. Tracheal intubation

of morbidly obese patients: LMA CTrach vs direct laryngoscopy. *Br J Anaesth* 2006; **97**: 742–5.

62. Keller C, Brimacombe J, Kleinsasser A, Brimacombe L. The Laryngeal Mask Airway ProSeal(TM) as a temporary ventilatory device in grossly and morbidly obese patients before laryngoscope-guided tracheal intubation. *Anesth Analg* 2002; **94**: 737–40.
63. Della Puppa A, Pittoni G, Frass M. Tracheal esophageal combitube: a useful airway for morbidly obese patients who cannot intubate or ventilate. *Acta Anaesthesiol Scand* 2002; **46**: 911–3.

Chapter 13

Ventilatory strategies during anesthesia

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13.1 Introduction

Morbid obesity results in physiologic derangement of the respiratory system, which poses significant challenges to the anesthesiologist for safe intraoperative ventilation. The development of atelectasis, which occurs within minutes after induction of anesthesia even in normal weight patients, is exaggerated in obese patients, and it is the main contributor to intra-operative increases in intra-pulmonary shunt and decreases in partial pressure of arterial oxygen (PaO_2) [1, 2]. To improve intraoperative PaO_2 or to avoid excessive hypercapnia, anesthesiologists typically increase the minute ventilation by increasing tidal volume (VT). However, this maneuver increases ventilatory airway pressure, which, if excessive, may induce micromechanical, parenchymal, stress-causing, ventilator-associated lung injury (VALI) [3].

In this chapter, we discuss respiratory system mechanics and gas exchange during anesthesia of morbidly obese (MO) patients; we also describe ventilatory strategies that can improve oxygenation while protecting the lungs from ventilator-induced mechanical stress. These protective strategies limit the degree of lung collapse and overdistention, and they may lead to improved clinical outcomes. To implement the most appropriate protective strategy, anesthesiologists must have an understanding of respiratory physiology of MO anesthetized patients.

13.2 Respiratory system mechanics in obese patients during anesthesia

In all subjects, merely changing from the upright to the supine position causes a marked reduction in lung volume and decreases respiratory system compliance, and these effects are magnified in obese patients [4–6]. Compared with normal weight subjects, MO patients have considerably reduced mean lung volumes during post-operative sedation and paralysis; functional residual capacity (FRC) also is reduced, and this is directly associated with decreases in lung and chest wall compliance [7]. In anesthetized obese patients, FRC decreases to approximately 50% of the pre-induction value [8]; this is accompanied by the rapid development of atelectasis in dependent lung regions because both the FRC and VT fall below the closing volume (Figure 13.1). The resultant atelectasis, which may persist post-operatively for 24 hours or longer, contributes to reduction in respiratory system compliance [2].

The exaggerated effect of position is caused by reduction in compliance in the lungs and chest wall. Chest wall compliance decreases as the weight of the large abdomen presses against the diaphragm and lower rib cage. Likely as a result of this primary effect, lung volume decreases and atelectasis develops, causing lung compliance to decrease [4–6]. General anesthesia causes a further decline in mean lung volume and respiratory system compliance, especially after induction of pneumoperitoneum (Figure 13.2) [9]. These decreases in compliance increase the airway pressure needed to produce adequate VT during positive-pressure breathing.

The reduced lung volume of obese patients is associated with decreased airway diameter, increased airway resistance, and enhanced expiratory flow limitation [7]. As a practical matter, airway pressure must be increased to produce adequate VT during positive-pressure ventilation.

13.2.1 Pneumoperitoneum and mechanics of breathing during laparoscopy

Increased intra-abdominal pressure (10–20 mm Hg) associated with pneumoperitoneum adversely affects pulmonary mechanics. Pneumoperitoneum shifts the diaphragm cephalad and imposes a resistive load against lung expansion during inspiration. Introduction

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

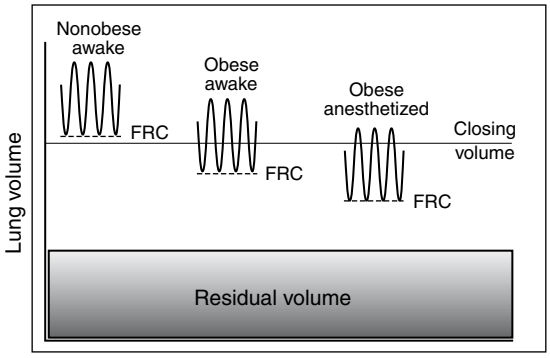

Figure 13.1 Effects of body weight and anesthesia on functional residual capacity (FRC): FRC declines with obesity and even more with induction of anesthesia. Tidal volume decreases below closing volume, resulting in faster onset of arterial hypoxemia.

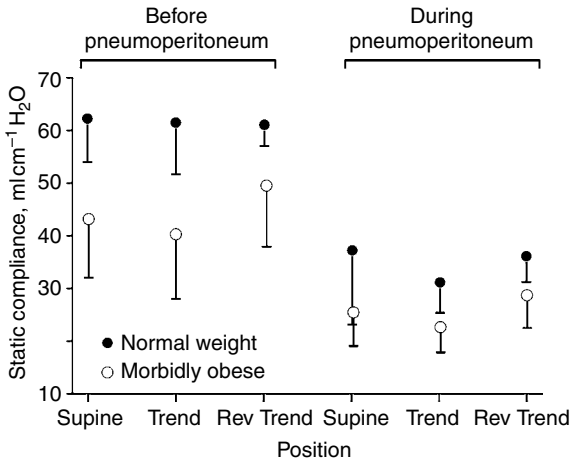

Figure 13.2 Effect of weight, body position, and pneumoperitoneum on respiratory system static compliance: After induction of anesthesia, static compliance is lower in morbidly obese patients. Pneumoperitoneum further decreases static compliance in obese and normal weight patients. Data are shown as mean and standard deviation. Rev indicates reverse; Trend, Trendelenburg position. Adapted from: Ref [9], with permission.

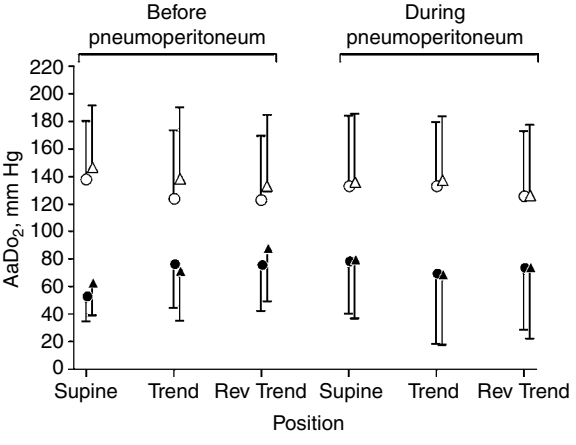

Figure 13.3 Effect of weight, body position, pneumoperitoneum, and tidal volume on alveolar-arterial oxygen difference ($AaDO_2$): Circles indicate a tidal volume of 600–700 ml; triangles indicate a tidal volume of 1200–1400 ml. Open symbols indicate morbidly obese patients; closed symbols indicate normal weight patients. Data are shown as mean and standard deviation. Rev indicates reverse; Trend, Trendelenburg position. Adapted from: Ref [16], with permission.

of pneumoperitoneum in MO patients further decreases static compliance of the respiratory system by up to 30% [9–11]. Additionally, induction of pneumoperitoneum increases intra-abdominal pressure, and because the abdominal compartment is mechanically coupled to the chest wall, chest wall compliance further decreases [12–14]. All these changes result in a large increase in end-inspiratory pressure (PEI), also termed "plateau pressure," measured during occlusion of the airway. Another study showed 50% and 81% increases in peak inspiratory pressure (PIP) and PEI, respectively, with the induction of pneumoperitoneum [15].

Thus, several factors (reduced compliances, increased resistances, and pneumoperitoneum) increase the airway pressure required during positive pressure ventilation in obese patients during anesthesia. High-pressure ventilation may cause parenchymal stress and disrupt lung structures. However, reduced chest wall compliance decreases transpulmonary pressure (the difference between alveolar and intrapleural pressure, a real distending force of the lungs), which protects the lungs from excessive distension and injury (volutrauma).

13.3 Alterations of gas exchange during anesthesia of morbidly obese patients

13.3.1 Intra-operative arterial oxygen tension (PaO_2)

After induction of anesthesia, deterioration of PaO_2 occurs in MO patients. Intraoperative impairment of PaO_2 correlates well with the degree of intrapulmonary shunt and the amount of atelectasis [1], although atelectasis is not the only cause of altered gas exchange during anesthesia. Of interest, introduction of pneumoperitoneum, which is associated with reduced respiratory system compliance (Figure 13.2), does not lead to further deterioration of alveolo-arterial oxygen tension difference [9–11] (Figure 13.3). A plausible explanation for the unchanged PaO_2 is that the

additional decrease in compliance is not due to further decreases in lung volume; rather, it is attributable to increased chest wall stiffness. Furthermore, pneumoperitoneum does not produce additional atelectasis beyond that associated with the induction of anesthesia. Similarly, changes in body position (Trendelenburg or reverse-Trendelenburg) do not affect PaO_2 significantly during laparoscopy [4, 9, 16]. This suggests that during pneumoperitoneum, no further recruitment or derecruitment of pulmonary parenchyma occurs by changing the body position. In contrast, gas exchange in obese patients during laparotomy (i.e., no pneumoperitoneum) is improved by placing the patient in the reverse Trendelenburg position [17]. During laparotomy, intra-abdominal pressure is atmospheric, and the reverse Trendelenburg position allows caudal displacement of the diaphragm, thereby increasing the mean lung volume and improving PaO_2.

13.3.2 Intra-operative arterial carbon dioxide tension

To maintain normocapnia, MO patients in the supine position require approximately 15% higher minute ventilation before initiation of pneumoperitoneum when compared with normal weight patients [9]. This increased ventilatory requirement is primarily attributable to increased physiologic dead space rather than to increased CO_2 production. Over a wide range of VT during pneumoperitoneum, MO patients have less efficient ventilation when supine. For example, as VT is increased in 100-ml increments, the partial pressure of arterial carbon dioxide ($PaCO_2$) decreases in normal weight patients by a mean of 5.3 mm Hg, but it decreases by only 3.6 mm Hg in MO patients [9]. Again, this is most likely because of increased physiologic dead space in obese patients. Thus, if normocapnia is to be maintained during anesthesia, VT or respiratory rate may need to be increased more in obese patients than in normal weight subjects, and this increase may lead to injurious airway pressure.

13.4 General principles of lung injury during mechanical ventilation

For normal weight and obese patients, prolonged mechanical ventilation with high pressure can induce mechanical stress and acute VALI [18, 19] (Figure 13.4). Fully developed VALI presents as bilateral pulmonary infiltrates consistent with edema in the absence of heart failure or severe, chronic lung disease [20]. The lung injury is thought to arise from alveolar overdistension, and from repetitive opening and closing of collapsed lung units during tidal ventilation. High ventilatory pressure during mechanical ventilation has been increasingly recognized as a marker of the stresses that may trigger VALI. These stresses can substantially stretch lung epithelial and endothelial cells (alveolar overdistension), disrupt the alveolocapillary membrane (volutrauma, barotrauma) (Figure 13.4), and cause pulmonary edema [21]. Equally damaging are lung injuries that occur when attempting to ventilate lung regions that are atelectatic (termed "low-volume injury" or "atelectotrauma"). Repetitive recruitment and derecruitment of atelectatic lung units creates high shear forces that disrupt endothelial and epithelial cells, leading to increased permeability of the alveolocapillary membrane and increased production of interleukin-1β, interleukin-6, interleukin-8, other inflammatory cytokines, and metalloproteinases ("biotrauma") (Figure 13.4) [22].

13.4.1 Association between mechanical ventilation and ventilator-associated lung injury in the intensive care unit setting

Several studies have shown that VALI has great clinical significance for patients in the intensive care unit (ICU). The use of high VT and a high respiratory rate are independent predictors of lung injury in patients with severe brain injury [23]. Of patients without preexisting lung injury who undergo mechanical ventilation for more than 48 hours, approximately one in four have evidence of VALI. One of the most important risk factors for VALI is the use of large VT (>12 ml kg^{-1}) [24]. Lowering VT in the ICU may decrease the frequency of VALI by up to two-fold [25].

13.4.2 Association between mechanical ventilation and post-operative ventilator-associated lung injury

Current evidence suggests large VT and high ventilatory pressure during anesthesia may increase the risk for lung injury, even during routine anesthesia in some high-risk patients. Post-operative VALI typically is observed within the first 3 days after surgery and more often affects patients who undergo high-risk procedures such as cardiac, vascular, or thoracic surgery. In patients undergoing thoracotomy, use of larger VT during one-lung ventilation is associated with higher incidence

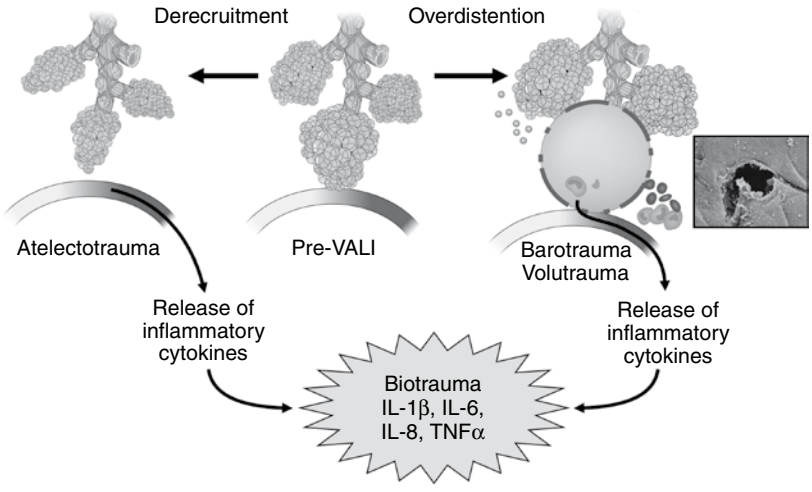

Figure 13.4 Acute lung injury may be attributable to derecruitment or overexpansion. Atelectasis (derecruitment) can result in repetitive opening and closing of lung units, leading to atelectotrauma and release of inflammatory cytokines. High tidal volume and overexpansion of lungs can rupture alveolo-capillary membranes (inset), leading to accumulation of neutrophils and release of inflammatory cytokines. IL indicates interleukin; TNF, tumor necrosis factor; VALI, ventilator-associated lung injury. (Inset adapted, with permission, from Hotchkiss JR, Simonson DA, Marek DJ, *et al.* Pulmonary microvascular fracture in a patient with acute respiratory distress syndrome. *Crit Care Med* 2002; **30**: 2368–70.

of post-operative respiratory failure [26]. In patients undergoing abdominal surgery, those who receive mechanical ventilation for more than 5 hours with high VT (12 ml kg^{-1}) and no positive end-expiratory pressure (PEEP) have leakage of plasma into alveoli, whereas patients with low VT (6 ml kg^{-1}) and 10 cm H_2O of PEEP do not [27]. The goal of this latter ventilatory strategy is to minimize mechanical stress to the lungs and to prevent atelectasis with PEEP. Alveolar-bronchial lavage from those patients ventilated with relatively high VT has higher levels of thrombin-antithrombin complexes and factor VIIa, both hallmarks of lung injury [27]. Similar results are observed when a lung-protective ventilatory strategy is applied to patients undergoing one-lung ventilation, with a decreased proinflammatory systemic response and improved post-operative lung function compared with conventional ventilatory strategies. This has clinical significance because tracheal extubation can be accomplished earlier [28].

13.4.3 Obesity and risk of ventilator-associated lung injury

To date, no clinical studies have examined whether obesity represents a risk factor for intra-operative VALI, but there are reasons to believe that this might be so. First, all patients have atelectasis that develops immediately after induction of general anesthesia and persists into the post-operative period, but this effect is exaggerated in obese patients [2]. Cyclic tidal recruitment and derecruitment in these areas and in areas that have collapsed at end expiration may lead to atelectotrauma. Second, lung size is correlated with ideal body weight, not with absolute weight [29]. If absolute body weight is used to calculate VT, obese patients may receive a higher VT relative to lung size. An unsubstantiated belief persists that MO patients require larger than usual VT during mechanical ventilation; this notion probably originates from early studies that used large VT to improve lung expansion in the obese. One multicenter analysis of patients receiving mechanical ventilation in the ICU showed that obese subjects received significantly higher VT per kilogram of ideal body weight than did normal weight patients [30]. The higher airway pressure may have increased risk of VALI for these patients. Third, to control the more profound hypercapnia that can occur with laparoscopy in obese patients, the tendency is to increase VT, which results in higher ventilatory pressure. Fourth, in the presence of atelectasis, even lower VT can overdistend non-atelectatic areas and cause lung injury. Indeed, alveolar injury may not occur in atelectatic alveoli; rather, it may occur in remote, non-atelectatic lung regions [31].

13.5 Intra-operative ventilatory strategies for morbidly obese patients

Intra-operative oxygenation in MO patients is largely determined by the magnitude of post-induction atelectasis. Thus, successfully increasing intra-operative PaO_2 depends on the ability to recruit atelectatic lungs and maintain the expansion. Fortunately, the lungs of most obese patients are relatively healthy, and regions of atelectasis can be recruited with proper ventilatory strategies. The main aims of mechanical ventilation in these patients are improvement of intra-operative gas exchange and avoidance of mechanical lung injury. During the past several decades, different strategies have been recommended for obese patients.

13.5.1 Strategy 1: High tidal volume

Intra-operative use of high VT was adopted decades ago as a measure to counteract atelectasis and hypoxemia in all anesthetized patients [32] and especially in obese patients [33], and this approach has been included in textbook recommendations ever since. In MO patients, ventilation with large VT results in intermittent increase of the lung volume above the closing volume (i.e., the lung volume below which a fraction of alveoli begins to collapse). However, several studies [15,16] were unable to show improvement of PaO_2 in obese patients receiving VT up to approximately 20 ml kg^{-1}; similar results have been observed in patients of normal weight. Intermittent lung inflation, regardless of the transient airway pressures achieved, likely is insufficient to reopen the collapsed alveoli – opening of collapsed alveoli requires more sustained (end-inspiratory or plateau) pressure that cannot be achieved with short or intermittent high-VT breaths.

Another reason why high VT does not consistently improve oxygenation is because alveolar ventilation is regionally heterogeneous during anesthesia [34]. All alveolar units do not have the same relative volume expansion, and the effect of this inhomogeneity is that alveoli in various parts of the lungs (mostly dependent alveoli) have different time constants. The time constant, defined as the time required to fill and empty alveoli, describes how quickly a lung region changes volume in response to changes in pressure. The time constant is calculated as follows: $t = R \times C$, where t indicates the time constant (in seconds); R, regional resistance (in [cm H_2O]/l sec^{-1}); and C, compliance (in l [cm H_2O]$^{-1}$). Within one time constant, the volume of a lung region reaches 63% of its equilibrium value (i.e., the volume maintained with steady state application of a given pressure), and within four time constants, equilibrium is nearly achieved [35]. Because of regional lung inhomogeneities and non-uniform ventilation, the variation in the filling and emptying of different lung regions results in a wide range of regional time constants. Therefore, in obese patients, intermittent (i.e., non-sustained) inflation, even at high VT, may not be sufficient to allow filling of collapsed alveoli during anesthesia.

13.5.1.1 Ventilatory pressures during high-VT ventilation

Lung distension is determined by transpulmonary pressure, the difference between the airway (alveolar) pressure and intra-pleural pressure, but intra-pleural pressure typically is not measured in clinical practice.

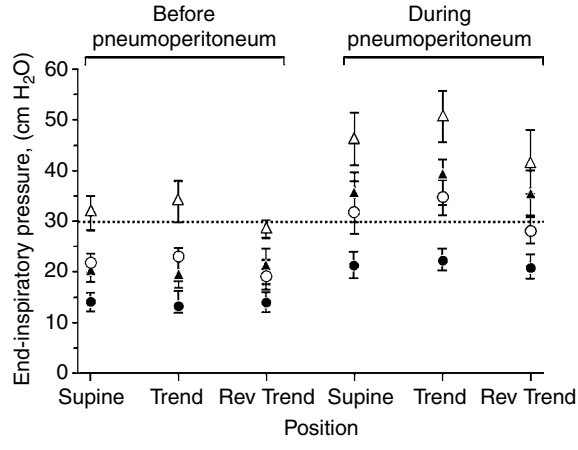

Figure 13.5 Effect of weight, body position, abdominal insufflation, and tidal volume on end-inspiratory pressure: End-inspiratory pressure during prolonged mechanical ventilation ideally should be maintained below 30 cm H_2O. Circles indicate a tidal volume of 600–700 ml; triangles indicate a tidal volume of 1200–1400 ml. Open symbols indicate MO patients; closed symbols indicate normal weight patients. Data are shown as mean and standard deviation. Rev indicates reverse; Trend, Trendelenburg position. Adapted from: Ref [16] with permission.

High ventilatory pressures may cause lung overdistension; this is the main risk factor for mechanical injury. For a given respiratory system compliance, the magnitude of lung distension is estimated from the PEI measured during occlusion of the endotracheal tube during no-flow conditions. PEI is a better estimate of distending pressures applied to the alveolus than PIP, which also includes a component determined by respiratory system and endotracheal-tube resistances. Nonetheless, high PIP usually is associated with high PEI. Prolonged use of very high PIP (50 cm H_2O) may lead to progressive impairment of pulmonary mechanics and acute respiratory failure [36]. An absolute upper limit for an acceptable PEI is difficult to define, but values of 30 to 35 cm H_2O have been recommended as the upper limit [37, 38]. Ventilation of MO patients with large VT, especially during pneumoperitoneum, may result in PEI that exceeds these values [16] (Figure 13.5). However, because chest wall compliance is lower in obese patients, a high PEI is not always indicative of high transpulmonary pressure; thus, the lung may not be stressed excessively. Therefore, reduced chest wall compliance may protect obese patients from volutrauma, and the high ventilatory pressures that produce lung injury in patients of normal weight may in fact be well tolerated in obese patients.

In conclusion, large VT does not improve PaO_2 in MO patients. No patient with normal lungs would

benefit from or need a VT exceeding 10 ml kg^{-1} of ideal body weight because high ventilatory pressures could trigger lung injury. The goal of mechanical ventilation is to maintain a PEI less than 30 cm H_2O. If necessary, a mild degree of hypercapnia is acceptable to meet this goal. Hypercapnia itself may have other benefits. For example, intra-operative hypercapnia in MO patients appears to decrease the frequency of wound infections by increasing tissue oxygenation [39].

13.5.2 Strategy 2: Positive end-expiratory pressure

Although experimental evidence overwhelmingly supports the use of PEEP during mechanical ventilation of diseased lungs [40], its specific application in clinical practice during anesthesia of MO patients with normal but acutely atelectatic lungs remains poorly defined. No consensus has been reached regarding the optimal level of PEEP for these patients, nor is it known whether PEEP should be adjusted to achieve a specific physiologic end point such as optimized PaO_2. Application of high PEEP theoretically is beneficial for patients with potentially recruitable areas of atelectatic lungs [41]. Because atelectasis is especially prominent during anesthesia of MO patients, PEEP is an attractive treatment method. Indeed, two studies showed that PEEP may be modestly beneficial, and that 10 cm H_2O PEEP improved PaO_2 in MO patients [42, 43] (Figure 13.6).

However, the effects on PaO_2 attributed to isolated application of PEEP in obese patients are inconsistent. One study showed no benefit of 10–12 cm H_2O PEEP on PaO_2 in MO patients [44]; in contrast, the discontinuation of PEEP improved PaO_2. The positive effects of PEEP include recruitment of lung units, improvement of ventilation–perfusion ratio (VA/Q) mismatching, and reduction in intra-pulmonary shunt. However, because PEEP can redirect the blood to non-ventilated lung units or decrease cardiac output, its effects on oxygenation may be unpredictable [44, 45]. In addition, any positive effects of PEEP on PaO_2 are likely to be short lived; within 1 min after cessation of PEEP, atelectasis reoccurs [46]. Thus, although PEEP may modestly improve gas exchange in obese patients, this effect is inconsistent and may have deleterious hemodynamic consequences.

13.5.3 Strategy 3: Alveolar recruitment maneuvers

The most efficient method of improving PaO_2 is to increase end-expiratory lung volume by judiciously re-expanding atelectatic lung areas with high, sustained, positive airway pressure. This maneuver is called a "vital capacity" maneuver or an "alveolar recruitment" maneuver. To open collapsed alveoli of healthy, non-obese patients during anesthesia, an initial pressure of at least 40 cm H_2O is needed [47]. This sustained pressure is termed "critical opening pressure" (P_{crit}) [48]. To re-expand atelectatic lungs and maintain expansion, three conditions must be fulfilled: 1) insufflation pressure must exceed P_{crit}; 2) inspiratory pressure must be sustained because considerable time is required for alveoli to open (i.e., the time constant for opening is relatively long); and 3) to maintain open alveoli, recruitment needs to be followed by adequate levels of PEEP [47].

The efficiency of the recruitment maneuver depends on the level of distension pressure applied and on the nature of the lung pathology; lung consolidation (acute respiratory distress syndrome [ARDS] and pneumonia) is more refractory to recruitment than the atelectasis formed in healthy lungs when anesthesia is induced in MO patients. The pressure applied to alveoli for distension is approximately equal to the transpulmonary pressure, which is estimated from PEI. However, the difference between transpulmonary pressure and PEI is greater in obese patients because of their decreased chest wall compliance [13, 14, 49]. As a consequence, a greater proportion of applied airway pressure is dissipated in distending the chest wall rather than in the lung, and the transpulmonary pressure is

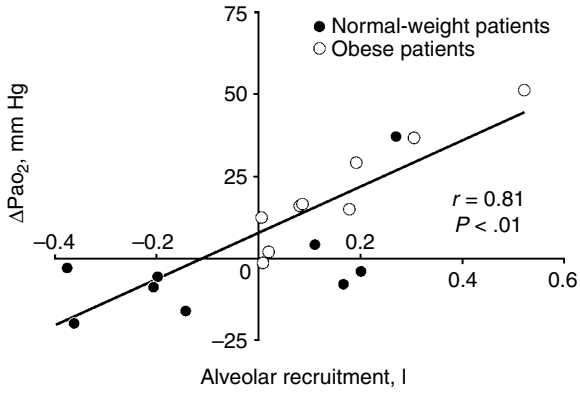

Figure 13.6 Relationship between arterial oxygen tension (ΔPaO_2) and alveolar recruitment. With 10 cm H_2O PEEP in normal weight and obese patients. Alveolar recruitment is associated with increase in PaO_2 only in obese patients. The regression line ($r = 0.81$) was calculated using data from normal weight and obese patients, but only the obese patients had statistically significant differences (obese patients only, $r = 0.91$, $p < 0.01$). Adapted from: Ref [42] with permission.

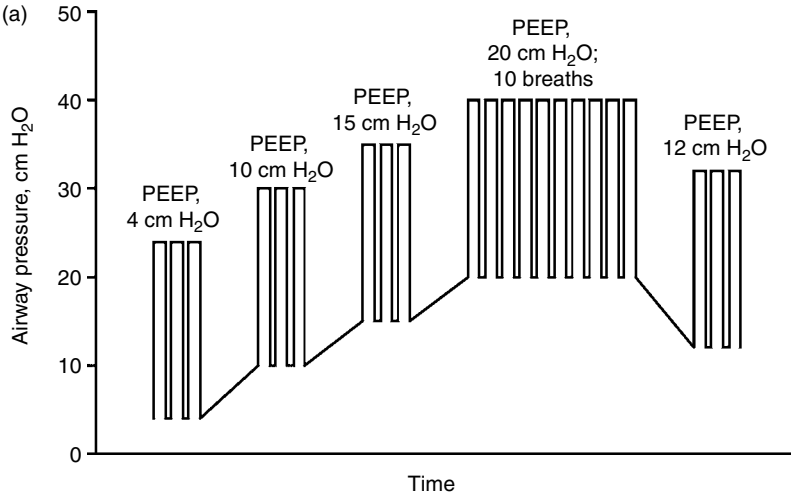

Figure 13.7a Mechanics of performing the recruitment maneuver by using a ventilator. This technique represents a modified alveolar recruitment method described by Tusman *et al.* [51]. Adapted from: Ref [50], with permission.

lower (and intra-pleural pressure higher) for any level of PEI. Therefore, MO patients may be able to tolerate higher PEI during ventilation without increasing the risk of lung overdistension. Furthermore, MO patients likely will require a higher PEI to recruit atelectatic areas of the lung.

13.5.4 Conducting the alveolar recruitment maneuver

Recruitment of the lungs may be performed manually by closing the anesthetic circuit and using the anesthesia reservoir bag to apply continuous insufflation pressure above the P_{crit} (40 cm H_2O in normal weight patients [48]). Additional pressure may be required for MO patients.

Alveolar recruitment also can be achieved by using a conventional mechanical ventilator. The selected VT may be based on ideal body weight [50] or can be higher [51]. While maintaining ventilation in a volume-controlled mode, PEEP is increased in a gradual, stepwise manner up to 15 cm H_2O in normal weight patients [51, 52] or to 20 cm H_2O in obese patients [50, 53]. To allow reopening of atelectatic lung areas, a larger number of breaths should be performed at the highest levels of PEEP [5, 6, 9] (Figure 13.7a).

Upon achievement of lung recruitment with either technique, mechanical ventilation should be continued with lower VT (6–8 ml kg^{-1} of ideal body weight) and higher PEEP (12 cm H_2O) [50, 53]. This ventilation technique results in PEI within the recommended limits (less than 30 cm H_2O) [54]. The recruitment maneuver efficiently improves intra-operative PaO_2 in obese patients [50, 53]; however, even 12 cm H_2O of PEEP cannot guarantee maintenance of lung re-expansion, and recruitment often needs to be repeated if the course of anesthesia is prolonged [50, 53]. The hemodynamic response needs to be closely monitored during application of sustained high airway pressure because hypotension and bradycardia may ensue.

13.5.5 Risks and benefits of alveolar recruitment maneuvers

Recruitment maneuvers are not without risk. The sustained high pressure in the airway may increase stress on non-atelectatic regions of the lung and cause volutrauma. The potential clinical significance of this mechanism is not known. Cardiovascular effects of high PEEP, including hypotension and decreased cardiac output, are well known.

Besides achieving an immediate short-term benefit in gas exchange (improvement in PaO_2), it is unknown whether lung recruitment offers any long-term benefit (Figure 13.7b). Improved tissue oxygenation may reduce post-operative wound infection in MO patients [39]. In animal models, the recruitment maneuver prevents lung injury and improves survival [55]. A randomized controlled trial showed that recruitment improved PaO_2 intra-operatively and post-operatively (24 hours), but PaO_2 immediately after tracheal extubation was not affected [56]. Other studies showed that the positive effect of recruitment on PaO_2 ceased within minutes upon arriving in the recovery room, but PaO_2 was not monitored after dismissal from the recovery room [50, 53]. In contrast to MO patients [50, 53], the re-expanded atelectatic tissue of non-obese patients with healthy lungs remains partially inflated for at least

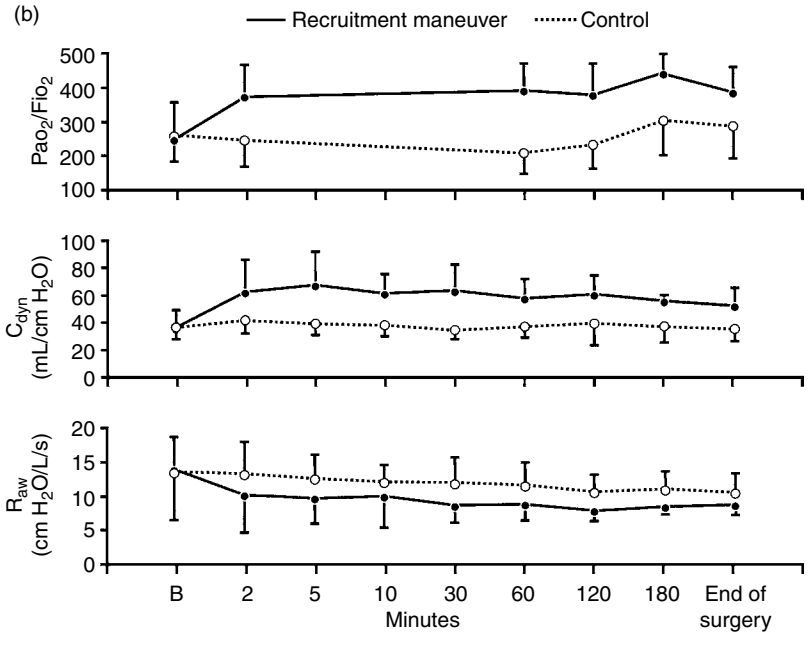

Figure 13.7b Arterial oxygen partial pressure as a fraction of inspiratory oxygen concentration (PaO_2/FiO_2), dynamic respiratory system compliance (C_{dyn}), and airway resistance (R_{aw}) in control and recruitment groups. PaO_2/FiO_2 and C_{dyn} increased and R_{aw} decreased after recruitment and remained greater compared to control patients throughout the operation. Recruitment maneuvers were performed at 2, 60, 120, and 180 minutes. Data are shown as mean and standard deviation. Adapted from: Ref [53], with permission.

40 minutes [57]. It is not known whether lung expansion can be maintained in MO patients by routine use of continuous positive airway pressure (CPAP) immediately after tracheal extubation. However, evidence is accumulating that the use of non-invasive ventilation with CPAP and bilevel positive airway pressure does avert post-extubation respiratory failure [58, 59]; it is not known whether this is related to a reduction in lung atelectasis.

13.6 Monitoring recruitment

Maintenance of recruitment in atelectatic lungs is not guaranteed. Positive end-expiratory pressure after recruitment delays the reoccurrence of atelectasis, but it likely does not prevent it. Positive end-expiratory pressure may affect gas exchange in ways beyond those mediated by atelectasis. Much of the knowledge regarding monitoring the effects of recruitment is from studying patients with ARDS [60]; lung expansion with recruitment maneuvers has not been quantified in MO patients undergoing anesthesia. Nonetheless, assessment tools used in patients with ARDS are based on widely used respiratory physiologic tests, and they therefore should be valid for the assessment of lung recruitment in MO patients.

In patients with ARDS, CT is the diagnostic standard for estimating alveolar anatomic recruitment (it also may provide insight into regional aeration inhomogeneity); however, this method is not practical for routine peri-operative use [41]. Similarly, regional measurement of the pressure–volume (PV) relationship and electrical impedance tomography are not practical methods for evaluation of lung recruitment because they are too complex for routine use [61]. For anesthesiologists, it is more important to have a simple bedside test that measures functional recruitment and helps optimize the proportion of the lungs participating in gas exchange. Therefore, the most useful bedside tests are those that monitor gas exchange, with or without concurrent measurements of simple lung mechanics. These tests are global measures of lung function, and while they may be less than optimal for evaluation of recruitment in patients with acute lung injury, they may be more appropriate for evaluation of reversal of intra-operative atelectasis such as those occurring in MO patients.

13.7 Assessment of recruitment using gas exchange

Recruitment followed by PEEP increases end-expiratory lung volume by increasing the proportion of aerated alveoli or by further inflating already ventilated lung regions, which may improve PaO_2. The level of PEEP that maximizes the delay of atelectasis re-formation in obese patients is not known. The level of PEEP that maximizes PaO_2 may coincide with optimal anatomic lung re-expansion, but this relationship is not guaranteed [41]. "Anatomic" and "functional"

lung recruitment are partially dissociated because of the complex effects of PEEP on factors such as cardiac output, regional blood flow redistribution from high to low VA/Q regions, and other effects on VA/Q [60]. Thus, oxygenation per se may not be directly correlated with the amount of atelectasis and the adequacy of recruitment.

$PaCO_2$ is correlated with effective ventilation, and an acute decrease in $PaCO_2$ after recruitment indicates improvement (decrease) of physiologic dead space. In fact, decreased $PaCO_2$ appears to be a more consistent and sensitive marker of recruitment than improved PaO_2 [62]. Although this method may be limited if CO_2 production changes, CO_2 production does not increase in morbidly obese patients and usually does not fluctuate acutely. Unfortunately, monitoring of $PaCO_2$ as a measure of recruitment during laparoscopic procedures may be a less reliable indicator of recruitment because of variable systemic absorption of CO_2. Monitoring PaO_2 or $PaCO_2$ levels to indirectly assess the effectiveness of recruitment has limitations; however, simultaneous monitoring (increase in PaO_2 and decrease in $PaCO_2$) may be a more sensitive indicator of recruitment [60].

13.8 Assessment of recruitment using lung mechanics

13.8.1 Respiratory system compliance

When the atelectatic lung is reopened with the recruitment maneuver, respiratory system compliance increases. The improvement in compliance directly correlates with the amount of healthy lung recruitment, and compliance therefore has been suggested as an indicator of lung recruitment [41]. However, respiratory system compliance, measured during tidal ventilation, may decrease with excessive use of PEEP and high VT that leads to alveolar overdistention.

Because ventilation at the extremes of lung volume decreases respiratory system compliance (a plot of respiratory system volume vs. applied pressure shows a sigmoidal relationship), the concept of "best compliance" that simultaneously coincides with improved PaO_2 and lowered $PaCO_2$ has been suggested as a clinical indicator of optimal recruitment without overdistention [60]. However, this concept has proved less useful than hoped in the treatment of patients with ARDS, and it has not been linked to improved outcomes [63, 64]. In MO patients, the increases in compliance are reliably related to improvements in PaO_2 [50, 53]. A physiologic rationale for these observed differences may be due to different types of ventilation inhomogeneity between patients with ARDS and MO patients with relatively normal lung tissue.

13.8.2 Measurements of compliance

Some commercial ventilators have built-in algorithms that calculate and display respiratory system compliance. Alternatively, respiratory system dynamic compliance ($C_{dynamic} = V_{Texpiratory} / PIP - PEEP_{total}$) or static compliance ($C_{static} = V_{Texpiratory} / PEI - PEEP_{total}$) can be easily calculated at the bedside. The highest compliance after recruitment, which coincides with the highest ratio of PaO_2 to fractional inspired oxygen concentration (FIO_2), should be maintained to keep the lungs open. A gradual decrease in compliance during surgery suggests reoccurrence of lung collapse and indicates when the recruitment should be performed again. Manipulation of VT and measurement of compliance may suggest the region of the PV curve at which ventilation is occurring. If a decrease in VT increases compliance, this suggests that the lung volume is near the upper part of the PV curve. An unchanged compliance indicates tidal cycling is in the linear (optimal) range of the PV curve. If compliance decreases as the VT is lowered, mean lung volume is likely cycling near the lower range of the PV curve [37] (Figure 13.8.)

Analyses of the relationship between applied pressure and lung volume can be valuable for the quantification of recruitment [12, 65, 66]. These techniques involve measurements taken during incremental or quasi-static (i.e., very slow) increases and decreases in airway pressure. Recruitment assessed in this manner correlates relatively well with the diagnostic standards established by computed tomography. Unfortunately, measurement and interpretation of respiratory system mechanics in this manner are complex tasks that require considerable expertise and equipment [67], and this tool currently is more suitable for research applications than for clinical bedside testing [66]. However, such techniques may become more practical in the future because newer ventilators such as those used in the ICU are increasingly equipped with software that enables routine calculation of PV curves.

13.8.3 Stress index monitoring

An alternative method for determining the optimal level of PEEP to maintain lung recruitment is to monitor the stress index [68] (Figure 13.9). The stress index is determined with each breath during constant-flow ventilation by analyzing the airway opening pressure (P_{ao}) over

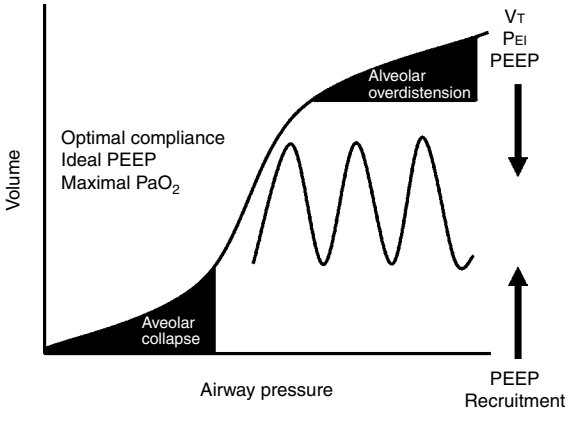

Figure 13.8 Pressure–volume curve illustrates the concept of lung-protective ventilation. Both overinflation and expiratory collapse should be avoided. PEI indicates end-inspiratory pressure; PEEP, positive-end-expiratory pressure; VT, tidal volume. Adapted from: Ref [74], with permission.

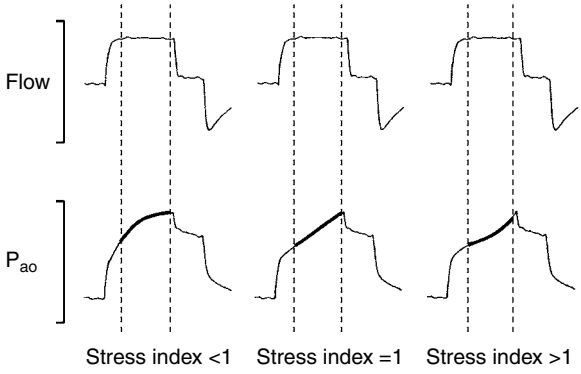

Figure 13.9 Assessment of recruitment by using the stress index: The stress index is determined by the segment of the P_{ao} curve (shown in bold) that corresponds to the period of constant-flow inflation (dotted lines) during volume-cycled, mechanical ventilation. A P_{ao} curve with progressively decreasing slope (downward concavity) suggests that recruitment is occurring. A P_{ao} curve with progressively increasing slope (upward concavity) indicates continuous decrease in compliance (i.e., lung is overdistending). A straight P_{ao} curve suggests absence of tidal variation in compliance (i.e., optimal tidal volume range). P_{ao} indicates airway opening pressure. Adapted from: Ref [68], with permission.

time (airway pressure–time curve). The shape of the airway pressure–time curve detects well tidal recruitment and hyperinflation [69]. This index assumes that the rate of change in P_{ao} over time reflects changes in respiratory system elastance (the reciprocal of compliance). If the airway pressure–time curve is linear (stress index = 1), this indicates that no recruitment is occurring (no tidal variation in compliance, the lung volume available for ventilation is not changing during the course of a breath). If this curve is exponential with downward concavity (progressive increase in slope; stress index <1), this suggests recruitment is occurring (continuous increase in compliance during inflation, the lung is underinflated). An upward concavity in this curve (progressive decrease in slope; stress index >1) suggests that the lung is overdistended at the end of the tidal breath (decrease in compliance). The stress index optimally is monitored after re-expansion of atelectasis because the index does not address the impact of P_{ao}. For this type of monitoring, a constant-flow ventilator that displays flow and airway pressure waveforms is necessary. With the introduction of more sophisticated ventilators, stress index monitoring will become more feasible.

13.8.4 Assessments of tests

Use of respiratory mechanics to optimize and monitor ventilatory settings may provide limited information about regional ventilation inhomogeneity. However, physiologic respiratory tests performed at the bedside to estimate the percentage of recruitable lung in patients with ARDS have poor specificity and sensitivity. For example, one study [60] showed that a simultaneous increase in the PaO_2/FiO_2 ratio and a decrease in $PaCO_2$ in response to recruitment maneuvers in patients with ARDS had a sensitivity of 71% and specificity of 59% for predicting lung recruitment (as determined by imaging). These tests may have higher specificity and sensitivity when applied to intra-operative recruitment of atelectatic but otherwise relatively healthy lungs of obese patients, but this has not been determined.

13.8.4.1 Alternative ventilatory techniques that may promote recruitment

Other ventilatory techniques such as inverse ratio ventilation, ventilation in a pressure-limited mode, dual control ventilation, and advanced closed-loop ventilation have gained varying degrees of popularity among ICU physicians. For MO patients, these modes theoretically have advantages over traditional ventilators, and as more sophisticated anesthesia ventilators become more common, their intra-operative use may become possible. However, little evidence suggests that these ventilatory modes markedly affect gas exchange under any condition.

13.9 Other measures that can minimize intra-operative atelectasis

Use of a high FIO_2 concentration (FIO_2, 1.0) during anesthesia accelerates the onset and the amount of atelectasis [70]. In normal weight patients, reducing

Table 13.1 Management of ventilation in MO patients

Action	Rationale or additional action
Atelectasis prevention during induction	
Restrict the use of FIO_2 to <0.8 Use of CPAP during induction	May help prevent development of resorption atelectasis and hypoxemia during apnea (induction).
Expansion of atelectasis	
Recruitment ("vital capacity") maneuver after intubation by using sustained (8–10 seconds) pressure ≥40 cm H_2O	Monitor for adverse effects (bradycardia, hypotension).
Monitor effects of recruitment	
Measure PaO_2 to confirm improvement of gas exchange Monitor improvement in lung compliance	Monitoring the effects of recruitment to assure optimal functional end point while preventing lung overdistension.
Keep the lungs recruited	
Use PEEP (10–12 cm H_2O)	Monitor for hypotension or decreasing arterial oxygenation (PEEP-induced increase in pulmonary shunt fraction).
Prevent reoccurrence of atelectasis	
Intermittent intra-operative re-recruitment	Monitor highest oxygenation and respiratory system compliance achieved after recruitment; a decline may be a sign of redeveloping atelectasis.
Avoid lung overdistension	
Use tidal volume 6–10 ml kg^{-1} of Ideal body weight Keep end-inspiratory pressure Below 30 cm H_2O Consider mild permissive hypercapnia if necessary	Increase the ventilation rate to control excessive hypercapnia instead of using large tidal volumes or high ventilatory pressures.
Maintain post-operative lung expansion	
Use CPAP or BiPAP immediately After tracheal extubation Keep the upper body elevated Maintain good pain control Use incentive spirometry Encourage early ambulation	Consider neuraxial analgesia or use of dexmedetomidine or other agents with few respiratory depression effects.

BiPAP, bi-level positive airway pressure; CPAP, continuous positive airway pressure; FIO_2, fractional inspired oxygen concentration; $PaCO_2$, partial pressure of arterial carbon dioxide; PaO_2, partial pressure of arterial oxygen; PEEP, positive end-expiratory pressure.

the FIO_2 below 0.8 minimizes development of atelectasis during the induction of anesthesia [71], but this approach has not been studied in obese patients. Even with a high FIO_2, the atelectasis that occurs after induction of anesthesia can be attenuated if PEEP is continuously applied throughout induction. This approach improves oxygenation during induction in obese patients [72]. One group of investigators [73] showed that 10 cm H_2O CPAP for 5 min before induction and 10 cm H_2O PEEP for 5 min after induction prevented formation of atelectasis and improved PaO_2 in MO patients. However, their technique involved mechanical ventilation for 5 min before tracheal intubation, which may be a prohibitive technique of induction for obese patients who may be difficult to mask ventilate or intubate (or both). In addition, this induction approach may facilitate gastric insufflation and pulmonary aspiration.

13.10 Summary of ventilation recommendations for obese patients

Table 13.1 summarizes various peri-operative strategies that provide "open-lung ventilation" and protect against ventilator-induced lung injury. Ideally, ventilation pressures should be adjusted such that the lungs are ventilated above the zone of derecruitment and below the zone of overdistension (Figure 13.8) [74]. Mean lung volume should increase with recruitment maneuvers, and subsequently higher levels of PEEP (10–12 cm H_2O) should be used to keep the lungs open. Clinically, higher levels of PEEP should be used only

if additional lung recruitment is evident (as shown by improved PaO_2). However, despite the use of high PEEP, atelectasis may reoccur, and recruitment maneuvers may need to be repeated during a prolonged course of anesthesia. To avoid lung overdistension, VT should be maintained at values less than 10 ml kg^{-1} of ideal body weight, and PEI should be below 30 cm H_2O. To achieve ventilation without excessive pressure, mild hypercapnia is permissible.

13.11 Conclusion

High VT without PEEP during mechanical ventilation may cause subclinical lung injury. For MO patients, a protective ventilatory strategy incorporates prevention of atelectasis and lung overexpansion while using lower PEI. Currently, lung recruitment is known to improve intra-operative gas exchange, but potential long-term benefits have not been studied. It would be prudent to apply the lessons learned from clinical studies in ARDS, and anesthesiologists should adopt the concept of open-lung ventilation as a standard practice during anesthesia of morbidly obese patients.

References

1. Hedenstierna G, Tokics L, Strandberg A, *et al*. Correlation of gas exchange impairment to development of atelectasis during anaesthesia and muscle paralysis. *Acta Anaesthesiol Scand* 1986; **30**: 183–91.
2. Eichenberger A, Proietti S, Wicky S, *et al*. Morbid obesity and postoperative pulmonary atelectasis: an underestimated problem. *Anesth Analg* 2002; **95**: 1788–92.
3. Matthay MA, Bhattacharya S, Gaver D, *et al*. Ventilator-induced lung injury: in vivo and in vitro mechanisms. *Am J Physiol Lung Cell Mol Physiol* 2002; **283**: L678–82.
4. Pelosi P, Croci M, Ravagnan I, *et al*. The effects of body mass on lung volumes, respiratory mechanics, and gas exchange during general anesthesia. *Anesth Analg* 1998; **87**: 654–60.
5. Hedenstierna G, Santesson J. Breathing mechanics, dead space and gas exchange in the extremely obese, breathing spontaneously and during anaesthesia with intermittent positive pressure ventilation. *Acta Anaesthesiol Scand* 1976; **20**: 248–54.
6. Van Lith P, Johnson FN, Sharp JT. Respiratory elastances in relaxed and paralyzed states in normal and abnormal men. *J Appl Physiol* 1967; **23**: 475–86.
7. Pelosi P, Croci M, Ravagnan I, *et al*. Respiratory system mechanics in sedated, paralyzed, morbidly obese patients. *J Appl Physiol* 1997; **82**: 811–8.
8. Damia G, Mascheroni D, Croci M, *et al*. Perioperative changes in functional residual capacity in morbidly obese patients. *Br J Anaesth* 1988; **60**: 574–8.
9. Sprung J, Whalley DG, Falcone T, *et al*. The impact of morbid obesity, pneumoperitoneum, and posture on respiratory system mechanics and oxygenation during laparoscopy. *Anesth Analg* 2002; **94**: 1345–50.
10. Dumont L, Mardirosoff C. Effects of a pneumoperitoneum in the obese patient. *Eur J Anaesthesiol* 2000; **17**: 786–7.
11. Nguyen NT, Anderson JT, Budd M, *et al*. Effects of pneumoperitoneum on intraoperative pulmonary mechanics and gas exchange during laparoscopic gastric bypass. *Surg Endosc* 2004; **18**: 64–71.
12. Ranieri VM, Brienza N, Santostasi S, *et al*. Impairment of lung and chest wall mechanics in patients with acute respiratory distress syndrome: role of abdominal distension. *Am J Respir Crit Care Med* 1997; **156**: 1082–91.
13. Mutoh T, Lamm WJ, Embree LJ, *et al*. Volume infusion produces abdominal distension, lung compression, and chest wall stiffening in pigs. *J Appl Physiol* 1992; **72**: 575–82.
14. Fahy BG, Barnas GM, Flowers JL, *et al*. The effects of increased abdominal pressure on lung and chest wall mechanics during laparoscopic surgery. *Anesth Analg* 1995; **81**: 744–50.
15. Bardoczky GI, Yernault JC, Houben JJ, *et al*. Large tidal volume ventilation does not improve oxygenation in morbidly obese patients during anesthesia. *Anesth Analg* 1995; **81**: 385–8.
16. Sprung J, Whalley DG, Falcone T, *et al*. The effects of tidal volume and respiratory rate on oxygenation and respiratory mechanics during laparoscopy in morbidly obese patients. *Anesth Analg* 2003; **97**: 268–74.
17. Perilli V, Sollazzi L, Bozza P, *et al*. The effects of the reverse Trendelenburg position on respiratory mechanics and blood gases in morbidly obese patients during bariatric surgery. *Anesth Analg* 2000; **91**: 1520–5.
18. Carlton DP, Cummings JJ, Scheerer RG, *et al*. Lung overexpansion increases pulmonary microvascular protein permeability in young lambs. *J Appl Physiol* 1990; **69**: 577–83.
19. Tsuno K, Prato P, Kolobow T. Acute lung injury from mechanical ventilation at moderately high airway pressures. *J Appl Physiol* 1990; **69**: 956–61.
20. Bernard GR, Artigas A, Brigham KL, *et al*. The American-European Consensus Conference on ARDS: definitions, mechanisms, relevant outcomes, and clinical trial coordination. *Am J Respir Crit Care Med* 1994; **149**: 818–24.
21. Dreyfuss D, Saumon G. Ventilator-induced lung injury: lessons from experimental studies. *Am J Respir Crit Care Med* 1998; **157**: 294–323.

22. Gattinoni L, Caironi P, Carlesso E. How to ventilate patients with acute lung injury and acute respiratory distress syndrome. *Curr Opin Crit Care* 2005; **11**: 69–76.
23. Mascia L, Zavala E, Bosma K, *et al*. Brain IT group. High tidal volume is associated with the development of acute lung injury after severe brain injury: an international observational study. *Crit Care Med* 2007; **35**: 1815–20.
24. Gajic O, Dara SI, Mendez JL, *et al*. Ventilator-associated lung injury in patients without acute lung injury at the onset of mechanical ventilation. *Crit Care Med* 2004; **32**: 1817–24.
25. Yilmaz M, Keegan MT, Iscimen R, *et al*. Toward the prevention of acute lung injury: protocol-guided limitation of large tidal volume ventilation and inappropriate transfusion. *Crit Care Med* 2007; **35**: 1660–6.
26. Fernández-Pérez ER, Keegan MT, Brown DR, *et al*. Intraoperative tidal volume as a risk factor for respiratory failure after pneumonectomy. *Anesthesiology* 2006; **105**: 14–8.
27. Choi G, Wolthuis EK, Bresser P, *et al*. Mechanical ventilation with lower tidal volumes and positive end-expiratory pressure prevents alveolar coagulation in patients without lung injury. *Anesthesiology* 2006; **105**: 689–95.
28. Michelet P, D'Journo XB, Roch A, *et al*. Protective ventilation influences systemic inflammation after esophagectomy: a randomized controlled study. *Anesthesiology* 2006; **105**: 911–9.
29. Crapo RO, Morris AH, Gardner RM. Reference values for pulmonary tissue volume, membrane diffusing capacity, and pulmonary capillary blood volume. *Bull Eur Physiopathol Respir* 1982; **18**: 893–9.
30. O'Brien JM Jr, Welsh CH, Fish RH, *et al*; National Heart, Lung, and Blood Institute Acute Respiratory Distress Syndrome Network. Excess body weight is not independently associated with outcome in mechanically ventilated patients with acute lung injury. *Ann Intern Med* 2004; **140**: 338–45.
31. Tsuchida S, Engelberts D, Peltekova V, *et al*. Atelectasis causes alveolar injury in nonatelectatic lung regions. *Am J Respir Crit Care Med* 2006; **174**: 279–89.
32. Bendixen HH, Hedley-Whyte J, Laver MB. Impaired oxygenation in surgical patients during general anesthesia with controlled ventilation: a concept of atelectasis. *N Engl J Med* 1963; **269**: 991–6.
33. Visick WD, Fairley HB, Hickey RF. The effects of tidal volume and end-expiratory pressure on pulmonary gas exchange during anesthesia. *Anesthesiology* 1973; **39**: 285–90.
34. Koutsoukou A, Koulouris N, Bekos B, *et al*. Expiratory flow limitation in morbidly obese postoperative mechanically ventilated patients. *Acta Anaesthesiol Scand* 2004; **48**: 1080–8.
35. Waters DJ, Mapleson WW. Exponentials and the anaesthetist. *Anaesthesia* 1964; **19**: 274–93.
36. Kolobow T, Moretti MP, Fumagalli R, *et al*. Severe impairment in lung function induced by high peak airway pressure during mechanical ventilation: an experimental study. *Am Rev Respir Dis* 1987; **135**: 312–5.
37. Slutsky AS. Consensus conference on mechanical ventilation: January 28–30, 1993 at Northbrook, Illinois, USA. Part I. European Society of Intensive Care Medicine, the ACCP and the SCCM. *Intensive Care Med* 1994; **20**: 64–79. Erratum in: *Intensive Care Med* 1994; 20: 378.
38. Dellinger RP, Levy MM, Carlet JM, *et al*; International Surviving Sepsis Campaign Guidelines Committee; American Association of Critical-Care Nurses; American College of Chest Physicians; American College of Emergency Physicians; Canadian Critical Care Society; European Society of Clinical Microbiology and Infectious Diseases; European Society of Intensive Care Medicine; European Respiratory Society; International Sepsis Forum; Japanese Association for Acute Medicine; Japanese Society of Intensive Care Medicine; Society of Critical Care Medicine; Society of Hospital Medicine; Surgical Infection Society; World Federation of Societies of Intensive and Critical Care Medicine. Surviving Sepsis Campaign: international guidelines for management of severe sepsis and septic shock: 2008. *Crit Care Med* 2008; **36**: 296–327. Erratum in: *Crit Care Med* 2008; 36: 1394–6.
39. Hager H, Reddy D, Mandadi G, *et al*. Hypercapnia improves tissue oxygenation in morbidly obese surgical patients. *Anesth Analg* 2006; **103**: 677–81.
40. Amato MB, Barbas CS, Medeiros DM, *et al*. Effect of a protective-ventilation strategy on mortality in the acute respiratory distress syndrome. *N Engl J Med* 1998; **338**: 347–54.
41. Caironi P, Gattinoni L. [Use of positive end-expiratory pressure in acute respiratory distress syndrome: current views]. *Recenti Prog Med* 2007; **98**: 509–17. [In Italian].
42. Pelosi P, Ravagnan I, Giurati G, *et al*. Positive end-expiratory pressure improves respiratory function in obese but not in normal subjects during anesthesia and paralysis. *Anesthesiology* 1999; **91**: 1221–31.
43. Perilli V, Sollazzi L, Modesti C, *et al*. Comparison of positive end-expiratory pressure with reverse Trendelenburg position in morbidly obese patients undergoing bariatric surgery: effects on hemodynamics and pulmonary gas exchange. *Obes Surg* 2003; **13**: 605–9.
44. Salem MR, Dalal FY, Zygmunt MP, *et al*. Does PEEP improve intraoperative arterial oxygenation in grossly obese patients? *Anesthesiology* 1978; **48**: 280–1.
45. Luce JM. The cardiovascular effects of mechanical ventilation and positive end-expiratory pressure. *JAMA* 1984; **252**: 807–11.

46. Brismar B, Hedenstierna G, Lundquist H, *et al*. Pulmonary densities during anesthesia with muscular relaxation: a proposal of atelectasis. *Anesthesiology* 1985; **62**: 422–8.
47. Lachmann B. Open up the lung and keep the lung open. *Intensive Care Med* 1992; **18**: 319–21.
48. Rothen HU, Sporre B, Engberg G, *et al*. Re-expansion of atelectasis during general anaesthesia: a computed tomography study. *Br J Anaesth* 1993; **71**: 788–95.
49. Gattinoni L, Pelosi P, Suter PM, *et al*. Acute respiratory distress syndrome caused by pulmonary and extrapulmonary disease: different syndromes? *Am J Respir Crit Care Med* 1998; **158**: 3–11.
50. Whalen FX, Gajic O, Thompson GB, *et al*. The effects of the alveolar recruitment maneuver and positive end-expiratory pressure on arterial oxygenation during laparoscopic bariatric surgery. *Anesth Analg* 2006; **102**: 298–305. Erratum in: *Anesth Analg* 2006; 102: 881.
51. Tusman G, Böhm SH, Vazquez de Anda GF, *et al*. 'Alveolar recruitment strategy' improves arterial oxygenation during general anaesthesia. *Br J Anaesth* 1999; **82**: 8–13.
52. Tusman G, Böhm SH, Suarez-Sipmann F, *et al*. Alveolar recruitment improves ventilatory efficiency of the lungs during anesthesia. *Can J Anaesth* 2004; **51**: 723–7.
53. Sprung J, Whalen FX, Comfere T, *et al*. Alveolar recruitment and arterial desflurane concentration during bariatric surgery. *Anesth Analg* 2009; **108**: 120–7.
54. Hager DN, Krishnan JA, Hayden DL, *et al*. ARDS Clinical Trials Network. Tidal volume reduction in patients with acute lung injury when plateau pressures are not high. *Am J Respir Crit Care Med* 2005; **172**: 1241–5.
55. Duggan M, McCaul CL, McNamara PJ, *et al*. Atelectasis causes vascular leak and lethal right ventricular failure in uninjured rat lungs. *Am J Respir Crit Care Med* 2003; **167**: 1633–40.
56. Minkovich L, Djaiani G, Katznelson R, *et al*. Effects of alveolar recruitment on arterial oxygenation in patients after cardiac surgery: a prospective, randomized, controlled clinical trial. *J Cardiothorac Vasc Anesth* 2007; **21**: 375–8.
57. Rothen HU, Sporre B, Engberg G, *et al*. Reexpansion of atelectasis during general anaesthesia may have a prolonged effect. *Acta Anaesthesiol Scand* 1995; **39**: 118–25.
58. Budweiser S, Riedl SG, Jörres RA, *et al*. Mortality and prognostic factors in patients with obesity-hypoventilation syndrome undergoing noninvasive ventilation. *J Intern Med* 2007; **261**: 375–83.
59. El-Solh AA, Aquilina A, Pineda L, *et al*. Noninvasive ventilation for prevention of post-extubation respiratory failure in obese patients. *Eur Respir J* 2006; **28**: 588–95.
60. Gattinoni L, Caironi P, Cressoni M, *et al*. Lung recruitment in patients with the acute respiratory distress syndrome. *N Engl J Med* 2006; **354**: 1775–86.
61. Victorino JA, Borges JB, Okamoto VN, *et al*. Imbalances in regional lung ventilation: a validation study on electrical impedance tomography. *Am J Respir Crit Care Med* 2004; **169**: 791–800.
62. Gattinoni L, Vagginelli F, Carlesso E, *et al*. Prone-Supine Study Group. Decrease in $PaCO_2$ with prone position is predictive of improved outcome in acute respiratory distress syndrome. *Crit Care Med* 2003; **31**: 2727–33.
63. Katz JA, Ozanne GM, Zinn SE, *et al*. Time course and mechanisms of lung-volume increase with PEEP in acute pulmonary failure. *Anesthesiology* 1981; **54**: 9–16.
64. Ranieri VM, Eissa NT, Corbeil C, *et al*. Effects of positive end-expiratory pressure on alveolar recruitment and gas exchange in patients with the adult respiratory distress syndrome. *Am Rev Respir Dis* 1991; **144**: 544–51.
65. Jonson B, Richard JC, Straus C, *et al*. Pressure-volume curves and compliance in acute lung injury: evidence of recruitment above the lower inflection point. *Am J Respir Crit Care Med* 1999; **159**: 1172–8.
66. Jonson B, Svantesson C. Elastic pressure-volume curves: what information do they convey? *Thorax* 1999; **54**: 82–7.
67. Chiumello D, Carlesso E, Aliverti A, *et al*. Effects of volume shift on the pressure-volume curve of the respiratory system in ALI/ARDS patients. *Minerva Anestesiol* 2007; **73**: 109–18.
68. Grasso S, Stripoli T, De Michele M, *et al*. ARDSnet ventilatory protocol and alveolar hyperinflation: role of positive end-expiratory pressure. *Am J Respir Crit Care Med* 2007; **176**: 761–7.
69. Grasso S, Terragni P, Mascia L, *et al*. Airway pressure-time curve profile (stress index) detects tidal recruitment/hyperinflation in experimental acute lung injury. *Crit Care Med* 2004; **32**: 1018–27.
70. Rothen HU, Sporre B, Engberg G, *et al*. Prevention of atelectasis during general anaesthesia. *Lancet* 1995; **345**: 1387–91.
71. Edmark L, Kostova-Aherdan K, Enlund M, *et al*. Optimal oxygen concentration during induction of general anesthesia. *Anesthesiology* 2003; **98**: 28–33.
72. Gander S, Frascarolo P, Suter M, *et al*. Positive end-expiratory pressure during induction of general anesthesia increases duration of nonhypoxic apnea in morbidly obese patients. *Anesth Analg* 2005; **100**: 580–4.
73. Coussa M, Proietti S, Schnyder P, *et al*. Prevention of atelectasis formation during the induction of general anesthesia in morbidly obese patients. *Anesth Analg* 2004; **98**: 1491–5.
74. Yilmaz M, Gajic O. Optimal ventilator settings in acute lung injury and acute respiratory distress syndrome. *Eur J Anaesthesiol* 2008; **25**: 89–96.

Chapter 14

Regional anesthesia and obesity

Pedro P. Tanaka and Jay B. Brodsky

14.1 Introduction

One consequence of the current worldwide obesity epidemic is that every day in every operating room and ambulatory treatment center, obese patients undergo all kinds of surgical procedures. Many of the same concerns that the anesthesia team has when anesthetizing a MO patient for a bariatric procedure are valid for these other operations as well. The challenge of managing a patient with significant medical co-morbidities and the potential for airway complications is always present. In addition, many MO patients have obstructive sleep apnea (OSA) syndrome and are extremely sensitive to the respiratory depressant effects of sedatives, opioids, and general anesthetic agents. This chapter reviews the use of regional anesthesia techniques in obese patients.

14.2 Regional anesthesia advantages

A successful regional anesthetic technique can offer distinct advantages over general anesthesia. The potential benefits of regional anesthesia are particularly important for the MO patient. These include minimal airway intervention, a reduction or even complete avoidance of cardiopulmonary depressant agents, less post-operative nausea and vomiting, and the possibility of improved post-operative analgesia, especially if a long-acting local anesthetic is used (Table 14.1). If complications from over-sedation are reduced, then both post anesthesia care unit (PACU) and overall hospital stays should also be decreased.

When performing a regional anesthetic there are considerations that are unique to the MO patient (Table 14.2). These include the technical challenge of identifying the appropriate nerve, or the epidural or intrathecal space in a patient whose anatomic landmarks may be obscured. Special equipment, such as longer needles, may be required. Obese patients can be difficult to move and position for a regional block. An inadequate or failed block may necessitate establishing an airway and performing general anesthesia, often in less than ideal conditions.

Table 14.1 Potential advantages of regional anesthesia

• Minimal intra-operative airway interventions
• Less cardiopulmonary depression
• Improved post-operative pain control
• Decreased opioid consumption
• Less post-operative nausea and vomiting
• Shorter PACU length of stay
• Shorter hospital length of stay
• Fewer unplanned hospital admissions
• Increased overall patient satisfaction

PACU, post anesthesia care unit.

Table 14.2 Regional anesthetic considerations for morbid obesity

• Difficulty moving and positioning the patient
• Increased technical difficulty performing a regional block:
• Obscured anatomic landmarks
• Inability to identify the epidural or subarachnoid spaces
• Increased frequency of vascular cannulation and/or "wet" tap during epidural placement
• May require ultrasonography
• Conventional needle may be too short
• Increased chance of inadequate or failed block – requiring conversion to general anesthesia

14.3 Neuraxial blocks

The most extensive experience with regional anesthetic techniques in obese patients is with neuraxial

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

(spinal and epidural) anesthesia. The majority of information we have on neuraxial anesthesia and obesity comes from obstetric patients, so any relevance to the obese non-obstetric population must be inferred [1, 2]. Routine use of neuraxial anesthesia for labor and delivery in obese parturients has become the norm since it reduces anesthesia-related maternal mortality[3].

14.3.1 Epidural anesthesia

Local anesthetic dose selection for any patient is important since too large a volume will increase the risk of hypotension and other potentially serious complications such as seizures and arrhythmias, but too small a dose may result in a failed block and the need for general anesthesia and tracheal intubation.

Experience in obstetrics suggests that the appropriate epidural dose of local anesthetic may be different for a MO patient than for a normal weight patient receiving a block at the same anatomic level. Obese patients require less local anesthetic than their normal counterparts to achieve a similar sensory level. This observation is based on several studies in which the same dose of local anesthetic, administered to obese and non-obese patients resulted in differences in neural blockade.

Following administration of 20 ml of 0.75% bupivacaine in the L_3–$_4$ interspace, there was a direct correlation between cephalad spread of analgesia and BMI [4]. The level was higher in obese patients. Obese parturients (BMI > 30 kg m^{-2}) in labor have significantly reduced epidural analgesic requirements, and have higher sensory blocks with similar dose of local anesthetic than normal weight patients [5]. Thus, it would seem prudent to administer local anesthetics in smaller volumes or in divided doses until an appropriate sensory block is achieved for any obese patient undergoing epidural anesthesia.

Not surprisingly, locating the epidural space is often technically more difficult in larger patients. In extreme obesity anatomic landmarks may be virtually impossible to identify manually. For a lumbar approach for either an epidural or spinal anesthetic, a cooperative patient can be asked to identify the "midpoint of your body". If they are able to place a finger at that site in their back, the spot they identify will be very close to the L_2–$_3L_3$–$_4$ interspaces (Figure 14.1) This method of having the patient identify their "midline" was successfully used for a patient with a BMI of 88 kg m^{-2} undergoing a ceasarian section under epidural anesthesia [6].

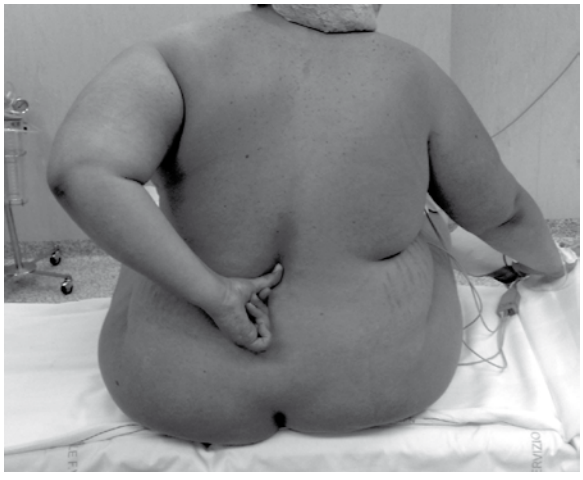

Figure 14.1 Anatomic landmarks may be difficult to identify. For a lumbar approach for either an epidural or spinal anesthetic, a cooperative patient can identify the "mid-point of the body" with their finger. That site will be very close to the L_2–$_3L_3$–$_4$ interspaces. (Photograph courtesy of Dr. Yigal Leykin, Pordenone, Italy)

More attempts are usually needed in an obese patient when trying to locate the epidural space. In one study of obstetric patients, 74% of those weighing > 300 pounds (136.4 kg) needed more than one attempt, and 14% required more than three attempts [7]. In another study the initial epidural catheter "failed" in 42% of MO parturients, but in only 6% of control patients. Misidentification of appropriate landmarks and anatomic distortion were implicated for the high initial failure rate in the obese group [8]. Similar results have been reported by others [9].

Position of the patient for needle placement can also be important. Four hundred and fifty obese parturients underwent continuous epidural analgesia during labor. During epidural catheter placement, patients were randomized into three groups; sitting (n = 150), horizontal lateral recumbent (n = 150) or lateral recumbent in a head-down position (n = 150) [10]. The lowest incidence of inadvertent vascular cannulation (1.3%) was in the lateral head-down group. The incidence of this complication in the sitting position (12.0%) and horizontal lateral position (12.9%) was much greater. Accidental sub-arachnoid puncture ("wet tap") was 2% in the lateral head-down position, 2% in the sitting position and 1.3% in the lateral position.

Increasing weight is significantly correlated with the depth or distance for placement of an epidural at

each of the usual epidural sites (lumbar, lower thoracic, upper thoracic) and with the different technical approaches (midline, paramedian) [11].

In most practices an epidural is performed with the patient in a sitting position. After the catheter has been successfully inserted and securely fixed to the skin with tape, the catheter tip position can change and actually be withdrawn from the epidural space while repositioning the patient to the lateral decubitus or supine position. The magnitude of catheter movement is greatest (> 1 cm) in obese patients (BMI > 30 kg m^{-2}) [12]. Catheter migration can have important implications. If a multi-orificed epidural catheter is used, it should be inserted a minimum of 4 cm into the epidural space in obese patients, since unrecognized catheter migration after changing patient position can result in a loss of anesthetic agent and an inadequate block [13].

The incidence of complications with epidural anesthesia increases with increasing weight. For example, inadvertent epidural venous puncture during placement occurs more frequently in obese parturients than non-obese patients, and this results in a higher incidence of multiple punctures [14]. More punctures increase the risk of the needle entering the sub-arachnoid space, a complication that can lead to post-dural puncture headache.

In a retrospective study of post-dural puncture headache in MO parturients who experienced a "wet tap" during epidural placement, obese patients had a 24% of incidence of headache compared to a 45% incidence in non-obese patients. The fewer headaches in obese parturients may be explained by their increased abdominal panniculus which raises abdominal pressure and slows cerebral spinal fluid (CSF) leak [15]. Obese patients may also be less active post-operatively so the symptoms of post-dural puncture headache might have been masked.

Ultrasonography (US) has been used to facilitate epidural needle placement in morbidly obese patients for pain treatment, and to improve epidural needle guidance in obese obstetric patients [16]. The use of US decreased the error rate in identifying the appropriate inter-vertebral level in overweight parturients (BMI 28 kg m^{-2}) undergoing epidural placement [17].

Even with US guidance, complications during epidural placement, such as vascular cannulation, dural puncture, and inadequate block, can and do occur in extremely obese patients [18]. Ultrasonography is a helpful adjunct, but its use does not guarantee successful outcome.

14.3.2 Spinal anesthesia

As with epidural anesthesia, obesity is an important factor influencing spinal anesthesia. Obese pregnant patients having spinal anesthesia with low doses of hyperbaric bupivacaine (7.5–10mg) experienced higher sensory blocks than non-obese patients [19].

Similarly, non-obstetric patients undergoing urologic procedures were given 4 ml of isobaric 0.5% bupivacaine at the L_{3-4} space. Once again, there was a positive correlation between height of the block and degree of obesity [20]. These authors postulated that in obese patients the vena cava is compressed from the weight of the abdominal contents, and that collateral circulation through the distended extradural veins reduced CSF volume.

Cerebral spinal fluid volume was measured in volunteers and smaller volumes were indeed found in obese subjects. However, MRI demonstrated that the increased abdominal pressure probably decreases CSF volume by displacing tissue into the vertebral canal through the inter-vertebral foramina rather than by changing venous volume [21]. Since CSF volume is less in obese patients than similar non-obese patients, the total volume of local anesthetic needed to achieve the same height of neural blockade should theoretically be less in obese than in normal weight patients.

The combination of the supine, Trendelenburg or lithotomy positions and a high spinal anesthetic can have serious consequences. Spinal anesthesia significantly reduces lung volumes in spontaneously breathing obese (BMI > 30 kg m^{-2}) patients scheduled for vaginal operations [22]. This reduction in peri-operative lung volumes, as assessed by spirometry, increases with increasing BMI and persists well into the recovery period, often outlasting the associated motor block [23].

Neuraxial anesthesia is often used in combination with general anesthesia during surgery to reduce the amount of inhalational and intravenous agents. Neuraxial anesthesia with local anesthetics, with and without opioids, provides an excellent means of reducing parenteral opioid requirements. This is especially important in MO patients, with and without OSA, who may be sensitive to the respiratory depressant effects of narcotics. One study did report that continuous spinal anesthesia in MO patients undergoing vertical banded gastroplasty was safe intra-operatively and provided satisfactory conditions in the immediate post-operative period [24]. These techniques are reviewed elsewhere in this book.

In some commercial spinal trays, the hub of the conventional spinal needle may not fit the hub of the introducer needle properly. This can effectively shorten the length of the needle by as much as 2 cm, an important concern for obese patients [25]. For many extremely obese patients, routine spinal needles may be too short and only special long spinal needles can reach the subarachnoid space.

As with epidural placement, bedside US assessment of the lumbar spine may facilitate the performance of spinal anesthesia in morbidly obese patients, particularly if no landmarks can be identified or a landmark-based approach has been unsuccessful [26]. Fluoroscopic imaging has also been used in an extremely obese patient to identify relevant landmarks, to approximate the distance to the intra-thecal space, and to confirm proper position of the spinal needle as it was advanced [27].

Reports of complications of spinal anesthesia in obese patients are once again limited to a few case reports or very small clinical series. For example, transient neurologic symptoms, described as leg or buttock pain, occurred more often in obese (BMI > 30 kg m^{-2}) than normal weight patients following spinal anesthesia with lidocaine [28].

14.4 Peripheral nerve blocks

As little information as we have on neuraxial blocks in obesity, there is even less data on peripheral nerve blocks in this population. A single large study considered 9342 peripheral nerve blocks in 7160 patients undergoing ambulatory surgery [29]. Patients were placed into four groups depending on their BMI (< 25 kg m^{-2}, 25–29 kg m^{-2}, 30–34 kg m^{-2}, > 35 kg m^{-2}). For risk adjustment the authors categorized regional anesthetic procedures into four subsets to combine blocks with similar characteristics: (1) centro-neuraxial blocks; (2) peripheral nerve blocks; (3) continuous peripheral nerve blocks; (4) paravertebral blocks. All peripheral nerve blocks were performed using a nerve stimulator technique. This study found that high BMI represented an independent risk factor for block failure necessitating supplementation, usually with general anesthesia.

In a subsequent publication by the same group consisting of almost the identical database, block failure (inability to provide surgical anesthesia), multiple attempts at the same block, and/or the need to supplement the block with local or general anesthesia was assessed in the different BMI categories. Problems occurred as follows: BMI < 25 kg m^{-2} = 9.5%, BMI 25–29 kg m^{-2} = 10.7%, and BMI ≥ 30 kg m^{-2} = 12.7% [30]. The risk-adjusted block failure rate for peripheral nerve blocks was statistically significantly higher in obese patients but not in overweight patients. Obesity was also associated with a statistically significant higher rate of complications related to local anesthetic toxicity or overdose, or from needle placement, but the overall complication rate was very low (0.3%) for all weight patients.

The length of stay in the PACU, pain scores in the PACU, incidence of post-operative nausea and vomiting, and unplanned admissions to the hospital were not different between any of the weight groups.

Pain with movement was actually significantly less in obese and overweight patients. Whether these results are related to increased pain tolerance, higher prevalence of diabetic neuropathy, or less extensive surgery in this subset of patients is unknown. A high level of overall satisfaction in the obese group clearly demonstrated that regional anesthesia techniques were well accepted among patients with increased BMI. A conclusion of this and other studies [31] is that overweight and obese patients should not be excluded from undergoing regional anesthesia in the ambulatory setting.

This conclusion was supported by a retrospective review of 258 morbidly obese patients (BMI > 35 kg m^{-2}) out of a total of 10 780 patients who underwent surgery with all types of anesthesia (including regional blocks) at an out-patient facility [32]. There were no differences in the rate of unplanned hospital admissions (3.0% vs. 2.7%) or post-operative complications between the MO and normal weight patients.

Another study investigated the impact of BMI on the success rate of supraclavicular block [33]. Their success rate in obese patients (94.3%) was high, but less than in the non-obese population.

As in normal weight patients, US can be invaluable help for performing successful peripheral nerve blocks [34, 35]. For interscalene brachial plexus blocks, US-guided identification of the nerves was almost identical between normal (BMI < 25 kg m^{-2}) and overweight (BMI > 25 kg m^{-2}) patients [36].

For any patient a misplaced block can have serious consequences. There is a single case report of phrenic nerve paralysis following interscalene brachial plexus block causing significant respiratory embarrassment in an obese patient [37].

The actual incidence of block complications, including those associated with acute local anesthetic overdose or toxicity (e.g., metallic taste, peri-oral paresthesia, tinnitus), central nervous system toxicity

Table 14.3 Principles in the anesthetic management of the obese patient

• Select a regional anesthesia technique when possible
• Anticipate problems and effectively prepare with appropriate equipment, monitors and personnel
• If general anesthesia becomes necessary, chose tracheal intubation and controlled ventilation
• Post-operative care should include close monitoring and early mobilization
• Judicious use of any opioid by any route

(e.g., excitation, seizures), and cardiovascular problems (e.g., hypotension, arrhythmias, cardiac arrest) in obese patients undergoing regional anesthesia remains unknown. Likewise, there are no data on other potential complications of regional anesthesia (e.g., hematoma at the site of the block, pneumothorax) in obese patients. In fact, although complications would seem to be more frequent in obese patients due to the technical challenges with needle placement and with local anesthetic dose requirements, the actual incidence of complications was low in the single large series that addressed these problems [30].

14.5 Conclusion

Unfortunately there have been very few studies describing regional anesthesia in obese patients, and even fewer reports for extremely obese patients. We do not know the true risks/benefits of regional anesthesia for MO patients. We currently do not know what are the safe and effective doses of local anesthetics in obesity, and whether they are similar or different from those needed for normal weight patients.

Although we can make some general recommendations for regional anesthesia in MO patients (Table 14.3), with so few studies actually available, our recommendations are based on the authors' biases.

References

1. Vallejo MC. Anesthetic management of the morbidly obese parturient. *Curr Opin Anaesthesiol* 2007; **20**: 175–80.
2. Soens MA, Birnbach DJ, Ranasinghe JS, *et al*. Obstetric anesthesia for the obese and morbidly obese patient: an ounce of prevention is worth more than a pound of treatment. *Acta Anaesthesiol Scand* 2008; **52**: 6–19.
3. Saravanakumar K, Rao SG, Cooper GM. Obesity and obstetric anaesthesia. *Anaesthesia* 2006; **61**: 36–48.
4. Hodgkinson R, Husain FJ. Obesity and the cephalad spread of analgesia following epidural administration of bupivacaine for Cesarean section. *Anesth Analg* 1980; **59**: 89–92.
5. Panni MK, Columb MO. Obese parturients have lower epidural local anaesthetic requirements for analgesia in labour. *Br J Anaesth* 2006; **96**: 106–10.
6. Patel J. Anaesthesia for LSCS in a morbidly obese patient. *Anaesth Intensive Care* 1999; **27**: 216–9.
7. Perlow JH, Morgan MA. Massive maternal obesity and perioperative cesarean morbidity. *Am J Obstet Gynecol* 1994; **170**: 560–5.
8. Hood DD, Dewan DM. Anesthetic and obstetric outcome in morbidly obese parturients. *Anesthesiology* 1993; **79**: 1210–8.
9. Ray A, Hildreth A, Esen UI. Morbid obesity and intrapartum care. *J Obstet Gynecol* 2008; **28**: 301–4.
10. Bahar M, Chanimov M, Cohen M, *et al*. The lateral recumbent head-down position for epidural catheter insertion decreases the incidence of epidural venous puncture in obese parturients. *Can J Anesth* 2004; **51**: 577–80.
11. Adachi YU, Sanjo Y, Sato S. The epidural space is deeper in elderly and obese patients in the Japanese population. *Acta Anaesthesiol Scand* 2007; **51**: 731–5.
12. Hamza J, Smida M, Benhamou D, *et al*. Parturient's posture during epidural puncture affects the distance from the skin to epidural space. *J Clin Anesth* 1995; **7**: 1–4.
13. Hamilton CL, Riley ET, Cohen SE. Changes in the position of epidural catheters associated with patient movement. *Anesthesiology* 1997; **86**: 778–84.
14. Ranta P, Jouppila P, Spalding M, *et al*. The effects of maternal obesity on labour and labour pain. *Anaesthesia* 1995; **50**: 322–6.
15. Faure E, Moreno R, Thisted R. Incidence of postdural puncture headache in morbidly obese parturients. *Reg Anesth* 1994; **19**: 361–3.
16. Wallace DH, Currie JM, Gilstrap LC, *et al*. Indirect sonographic guidance for epidural anesthesia in obese pregnant patients. *Reg Anesth* 1992; **17**: 233–6.
17. Schlotterbeck H, Schaeffer R, Dow WA, *et al*. Ultrasonographic control of the puncture level for lumbar neuraxial block on obstetric anaesthesia. *Br J Anaesth* 2008; **100**: 230–40.
18. Whitty RJ, Maxwell CV, Carvalho JC. Complications of neuraxial anesthesia in an extreme morbid obese patient for cesarean section. *Int J Obstet Anesth* 2006; **16**: 139–44.
19. Santos A, Pedersen H, Finster M, *et al*. Hyperbaric bupivacaine for spinal anesthesia in cesarean section. *Anesth Analg* 1984; **63**: 1009–13.
20. McCulloch WJ, Littlewoord DG. Influence of obesity on spinal analgesia with isobaric 0.5% bupivacaine. *Br J Anaesth* 1986; **58**: 610–4.
21. Hogan QH, Prost R, Kulier A, *et al*. Magnetic resonance imaging of cerebrospinal fluid volume and the influence

of body habitus and abdominal pressure. *Anesthesiology* 1996; **84**: 1341–9.

22. von Ungern-Sternberg BS, Regli A, Bucher E, *et al*. Impact of spinal anaesthesia and obesity on maternal respiratory function during elective Caesarean section. *Anaesthesia* 2004; **59**: 743–9.
23. Regli A, von Ungern-Sternberg BS, Reber A, *et al*. Impact of spinal anaesthesia on peri-operative lung volumes in obese and morbidly obese female patients. *Anaesthesia* 2006; **61**: 215–21.
24. Michaloudis D, Fraidakis O, Petrou A, *et al*. Continuous spinal anesthesia/analgesia for perioperative management of morbidly obese patients undergoing laparotomy for gastroplastic surgery. *Obes Surg* 2000; **10**: 220–9.
25. Corfe J. Length of spinal needles. *Anaesthesia* 2008; **63**: 444–5.
26. Prasad GA, Perlas A, Jinn K, *et al*. Ultrasound assisted spinal anesthesia in morbidly obese patients. *Anesthesiology* 2008; **109**: A339.
27. Eidelman A, Shulman MS, Novak GM. Fluoroscopic imaging for technically difficult spinal anesthesia. *J Clin Anesth* 2005; **17**: 69–71.
28. Freedman JM, Li D-K, Drasner K, *et al*. Transient neurologic symptoms after spinal anesthesia: an epidemiologic study of 1,863 patients. *Anesthesiology* 1998; **89**: 633–41.
29. Cotter JT, Nielsen KC, Guller U, *et al*. Increased body mass index and ASA physical status IV are risk factors for block failure in ambulatory surgery – an analysis of 9,342 blocks. *Can J Anaesth* 2004; **51**: 810–6.
30. Nielsen KC, Guller U, Steele SM, *et al*. Influence of obesity on surgical regional anesthesia in the ambulatory setting: An analysis of 9,038 blocks. *Anesthesiology* 2005; **102**: 181–7.
31. Raede J. Bariatric procedures as day/short stay surgery: is it possible and reasonable? *Curr Opin Anaesthesiol* 2007; **20**: 508–12.
32. Davies KE, Houghton K, Montgomery JE. Obesity and day-case surgery. *Anaesthesia* 2001; **56**: 1112–5.
33. Franco CD, Gloss FJ, Voronov G, *et al*. Supraclavicular block in the obese population: an analysis of 2020 blocks. *Anesth Analg* 2006; **102**: 1252–4.
34. Chantzi C, Saranteas T, Zogogiannis J, *et al*. Ultrasound examination of the sciatic nerve at the anterior thigh in obese patients. *Acta Anaesthesiol Scand* 2007; **51**: 132.
35. Duggan E, Brull R, Lai J, *et al*. Ultrasound-guided brachial plexus block in a patient with multiple glomangiomatosis. *Reg Anesth Pain Med* 2008; **33**: 70–3.
36. Schwemmer U, Papenfuss T, Greim C, *et al*. Ultrasound-guided interscalene brachial plexus anaesthesia: differences in success between patients of normal and excessive weight. *Ultraschall Med* 2006; **27**: 245–50.
37. Rau RH, Chan YL, Chuand HI, *et al*. Dyspnea resulting from phrenic nerve paralysis after interscalene brachial plexus block in an obese male – a case report. *Acta Anaesthesiol Sin* 1997; **35**: 113–8.

Section 4
Chapter
15

Post-operative conditions

Post-operative analgesia

Adrian Alvarez, Silvia E. Perez-Protto, Kathleen Carey and Ashish Sinha

15.1 Introduction

Currently, the majority of bariatric operations are performed laparoscopically. Laparoscopic surgery provokes less nociceptive stimulation than similar operations performed with an open incision. Accordingly, post-operative analgesia for acceptable pain control is different for laparoscopic compared to open operations.

Although laparoscopy is the preferred technique for bariatric surgery, in some cases (e.g., reoperation, previous abdominal surgery, lack of experience in laparoscopy) an open midline abdominal incision is necessary. MO patients may also need surgery for other conditions occurring more frequently in this population such as endometrial, prostate, or colon cancer.

Following open operations, the greater physical insult promotes a higher intensity of post-operative pain and an increased surgical-stress response [1]. More aggressive modalities of post-operative analgesia are usually necessary in these circumstances.

All MO patients need to become mobile as soon as possible after any surgery. Post-operative activity can be influenced by the level of pain following surgery. Adequate pain relief allowing the patients to cough, to take deep breaths, and to sit and to walk as early as possible may reduce the incidence of serious complications [2]. On the other hand, the amount of opioids necessary to provide efficient dynamic analgesia (acceptable pain relief with cough and ambulation) can result in opioid-related, dose-dependent side effects, including nausea, vomiting, sedation, prolonged ileus, and, especially, respiratory depression.

The common coexistence of respiratory disorders, such as obstructive sleep apnea (OSA) further complicates the analgesic management of the MO surgical patient. Obstructive sleep apnea is discussed in detail in other chapters.

In this chapter we will discuss different modalities for post-operative pain management in the MO patient undergoing laparoscopic and open abdominal surgery.

15.2 Non-neuraxial post-operative pain management modalities

In 1986, The World Health Organization (WHO) proposed guidelines for the selection of appropriate analgesic drug regimens. According to those guidelines, pain intensity should serve as the principal subjective measure that necessitates intervention [3].

Non-steroidal anti-inflammatory drugs (NSAIDs), acetaminophen, and aspirin can be used for mild to moderate pain. For pain of moderate or severe pain intensity, NSAIDs alone are not completely effective; therefore, opioids are often used along with non-opioid analgesics [3].

Currently, parenteral opioids are among the most effective analgesic techniques for the relief of moderate to severe pain. Opioids are still considered the treatment standard to provide analgesia for major surgeries associated with severe post-operative pain.

15.2.1 Opioid analgesia

Like any other surgical patient, adequate post-operative pain control for the MO is important not only for patient comfort and satisfaction, but also to reduce potential cardiopulmonary complications. Nevertheless, after surgery it may be difficult to determine the appropriate route of administration, dose, and/or system of delivery (intermittent, continuous, patient controlled analagesia [PCA]) for MO patients. Body composition, alterations in pharmacokinetics and dynamics, physiologic derangements and existence of co-morbidities may influence the outcomes. Optimization and individualization of opioid analgesic therapy is vital to provide satisfactory analgesia

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while avoiding potentially life-threatening risks, such as respiratory depression.

15.2.2 Oral route

Post-operative oral administration of analgesics is used after surgeries with low nociceptive impact, in the ambulatory surgery setting, and in those cases where, due to the normal post-operative recovery, systemic or regional administration is not longer necessary.

Oral absorption of drugs is essentially unchanged in obese patients [4]. The most common analgesic drugs given orally are NSAIDs and opioids. Non-steroidal anti-inflammatory drugs alone are only effective for treating mild pain, so for cases of moderate or severe pain, opioids are usually necessary.

15.2.3 Trans-dermal route

Fentanyl is a potent opiate analgesic that can be delivered trans-dermally via a skin patch. Since the patch provides slow and continuous drug delivery pain relief is less cyclical. However, a fixed dose is delivered and therefore titration to effect is not possible. Removing the patch will not reverse overdose effects once physical signs appear, and the patient will continue to absorb fentanyl into the body for more than 17 hours after the patch is removed. Consequently, fentanyl trans-dermal administration is not appropriate for post-operative analgesia.

15.2.4 Intra-muscular route

For the MO patient, IM injection of analgesic drugs is not recommended. Their effects are unpredictable, and the analgesia is not as effective as similar drugs given by other routes [2].

15.2.5 Intra-venous route

Intermittent IV bolus injections of opioids can be a therapeutic method for obese patients, although changes in the pharmacokinetic properties of these drugs must be considered. Careful titration is essential when administering parenteral opioids perioperatively to a MO patient [5].

In one study, Sprigge and colleagues found that continuous IV administration of pethidine was safe for post-operative analgesia in MO patients [6].

15.2.6 Opioid intra-venous/patient controlled analagesia

Determining the safe and effective opioid dose for MO patients is difficult because of the increased potential for these patients to develop respiratory depression. There must be a balance when individualizing analgesic therapy between optimal pain relief and side effects associated with too high plasma concentrations of analgesics [7].

Patient controlled analagesia was developed to allow IV administration of analgesics in an incremental fashion, so that respiratory depression and heavy sedation could be avoided [8]. The concept of on-demand analgesia was based on the premise that patients are best able to determine their need for analgesia to control their pain. IV/PCA morphine for MO patients undergoing bariatric surgery can be safe and effective [9].

In a prospective study of 25 MO patients undergoing open Roux-en-Y gastric bypass procedures (RYGB), patients were treated with morphine sulfate with IV/PCA post-operatively [9]. The PCA setting was set at morphine, 20 mcg/kg of ideal body weight (IBW), with a 10-minute lock out interval. The PCA was programmed to limit the administration to 80% of the maximum amount in a 4-hour time period. The authors reported that 24/25 patients were satisfied with their pain control on post-operative day (POD) 1. Analgesia was inadequate (Visual Analogue Scale [VAS] = 5.4 ± 2.1) on the day of surgery, but acceptable (VAS < 4) thereafter. Five patients experienced mild sedation on the day of surgery, and three patients experienced mild sedation on POD 1. No patient experienced respiratory depression in this study.

Despite the interesting findings in this study, there are some limitations. First, the number of subjects was too few (25 patients) to reliably and safely generalize the safe and effective use of morphine PCA. Second, this was a prospective non-randomized observational study; therefore the analgesic technique was not compared to any other treatment. Larger and randomized prospective controlled trials are necessary to determine if IV/PCA analgesia is a safe and effective choice for MO patients.

15.2.7 Multimodal opioid analgesia

Parenteral opioid administration remains the most common post-operative analgesic technique when given either continuously, intermittently, or via PCA. However, with unimodal opioid therapy it may be difficult to attain adequate analgesia without inhibiting other functions or producing undesirable side effects (e.g., sedation, respiratory depression, or nausea) [10].

Because pain from surgery has three major components (tissue injury, nociceptor stimulation, and

activation of central pathways) [11], a multimodal analgesic approach may be more effective than a unimodal technique.

The term multimodal analgesia refers to the simultaneous administration of multiple analgesic drugs or the same drugs by different delivery techniques. Because acute pain is an integrated process that is mediated by activation of numerous biochemical and anatomic pathways [12], a multimodal approach typically includes interventions such as local or neuraxial anesthesia, a NSAID, and/or an opioid.

By using a multimodal approach, the amount of individual analgesic drugs can be significantly reduced, while providing quality pain relief and simultaneously reducing the incidence of side effects. For the MO, this is of paramount importance.

Many different combinations and/or methods of administration can be used to reduce opioid requirements and related side effects.

Based on new evidence of efficacy and safety specific to weight loss surgery (WLS) patients, a panel of experts recommended the use of opioid-sparing, multimodal analgesic strategies, including local-anesthetic wound infiltration, and NSAIDs, unless contraindicated.

15.3 Multimodal non-opioid analgesia

Obese patients can be extremely sensitive to the respiratory-depressant effects of opioid analgesic drugs and are more likely than normal weight patients to require post-operative ventilation following surgery. It has been recommended that opioids be avoided for analgesia in OSA patients because of the increased risk of respiratory depression, and that alternative drugs should be used [14]. Many non-opioid drugs, including clonidine, ketamine, magnesium, lidocaine, ketorolac, and steroids, have each been shown to have analgesic effects. The combination of these drugs can potentiate analgesia by separate actions while decreasing the risk of side effects by lowering the effective dose for each individual agent.

In a prospective randomized study, Feld *et al.* studied the influence of two different anesthetic techniques on post-operative pain after open gastric bypass surgery [15]. Sedation, supplemental morphine use by PCA, and the need for continued ventilation in the post anesthesia care unit (PACU) were evaluated. General anesthesia was provided with sevoflurane in both groups. Patients were randomized with one group receiving IV fentanyl and the other group receiving a non-opioid drug regimen for intra-operative analgesia. Patients in the fentanyl group received intermittent boluses of 50 mcg IV up to a maximum dose of 6 mcg kg^{-1} IBW. Patients in the non-opioid group received a combination of ketorolac, clonidine, lidocaine, ketamine, magnesium sulfate, and methylprednisolone. Doses were calculated according to IBW [15].

This study reported that the non-opioid drug combination produced adequate anesthesia with less cardiovascular stimulation when compared to fentanyl analgesia. Mean arterial pressure was significantly lower in the non-opioid treated patients compared to fentanyl-treated patients. During surgery the end-tidal sevoflurane required to maintain equivalent anesthesia was lower in non-opioid treated patients. In the PACU, the non-opioid treated patients were less sedated, required less morphine by PCA and had similar pain scores compared to fentanyl patients. Two of the 15 fentanyl treated patients required controlled ventilation in the PACU compared to none of the non-opioid drug treated patients [15].

15.3.1 Dexmedetomidine

Dexmedetomidine is an alpha-2 agonist that works in a similar way to opioids by terminating efferent pain signals traveling from the brain to the substantia gelatinosa region of the dorsal horn of the spinal cord. The nerve terminals release norepinephrine, which produces hyperpolarization of nerve fibers. Like opioids this action further negates neurotransmitter release. Dexmedetomidine could be an option in the post-operative pain management of the MO patient. Its use intra-operatively may decrease the total amount of IV morphine needed post-operatively, and it resulted in a better outcome when compared to a placebo [16].

15.3.2 Other non-opioid analgesia modalities

15.3.2.1 Surgical site infusions

Bupivacaine infusion devices for continuous post-operative infiltration of the surgical wound have been developed to avoid the risk of respiratory depression associated with the administration of opioids. The ON-Q® pump (ON-Q Pain Management System, I-Flow Corporation, Lake Forest, CA, USA) provides a continuous infusion of local anesthetic and/or analgesic to surgical wound sites and/or in close proximity to nerves for pre-operative and post-operative regional anesthesia and/or pain management. The ON-Q device

has been used to administer combinations of bupivacaine/ketorolac, bupivacaine/ketorolac/morphine, and bupivacaine/dexmedetomidine. The pump holds up to 750 ml of medication, and infusion times can be programed to range from 12 hours to 5 days. There is both a selective flow mode as well as an on-demand setting that, like a PCA pump, allows the patient to self administer an extra 5 ml of medication in addition to the continuous basal rate. A bupivacaine pump has been used to reduce the use of opioids in MO undergoing laparoscopic bariatric surgery [17].

15.3.2.2 Humidified, warmed carbon dioxide insufflation

Several recent trials have studied the potential effects of heating and humidifying CO_2 for insufflation in laparoscopic surgery. Post-operative pain, core temperature and recovery room stay were evaluated [18,19). Regarding this method the European Association for Endoscopic Surgery practice guidelines states "the clinical benefits of warmed, humidified insufflation gas are minor and contradictory" [20].

A randomized, double blind, prospective controlled clinical trial was conducted to evaluate the effects of heat and humidity in MO patients undergoing CO_2 laparoscopy [21]. Patients undergoing laparoscopic RYGB were randomly assigned to receive either standard or warmed, humidified CO_2 insufflation. The primary endpoints were post-operative pain (measured by VAS) as well as total opioid use from a PCA pump.

In the control group, the abdomen was insufflated with room temperature non-humidified CO_2. In the study group, warm and humidified CO_2 was used for abdominal insufflation using a device (Insuflow Filter Heater Hydrator [Lexion Medical, St. Paul, MN]), which warmed the insufflated CO_2 to 35°C (95°F) at a relative humidity of 95% before insufflation. This study found that warmed, humidified CO_2 insufflation in bariatric patients undergoing L-RYGB was not associated with any significant benefit with regards to post-operative pain [21].

15.3.2.3 Continuous infusion of intra-peritoneal local anesthetics

Intra-peritoneal (IP) administration of local anesthetics has the potential to provide analgesia without the side effects of systemic opioids. In a randomized clinical trial the safety and efficacy of continuous IP infusion of bupivacaine was evaluated in MO patients undergoing laparoscopic adjustable gastric banding [22]. The treatment group received a continuous IP infusion of 0.375 % bupivacaine, while a control group received an IP infusion of 0.9% normal saline during the first 48 hours after surgery. A statistically significant decrease in VAS was noted in the IP infusion group (1.8 +/− 1.93 vs. control 3.5 +/− 2.4, $p < 0.046$) during the study period. There were no differences in the incidence of shoulder pain, additional morphine requirements, and/or antiemetic requirements [22].

15.4 Neuraxial post-operative pain management modalities

The most important alteration of respiratory function after anesthesia and surgery is decreased functional residual capacity (FRC). Decreased FRC (a common alteration in the MO) may result in atelectasis and ventilation-perfusion abnormalities leading to hypoxemia, pneumonia, and post-operative pulmonary complications. Patients most at risk are those with pre-existing pulmonary disease, advanced age, obesity, and those in severe pain.

MO patients are at a higher risk of respiratory depression from opioids than their lean counterparts. Therefore, when managing a MO patient undergoing open abdominal surgery, a reduced or opioid-free technique should be considered.

For lean individuals undergoing major open abdominal or thoracic operations, neuraxial anesthesia (epidural or spinal anesthesia)/analgesia has been demonstrated to provide better pain control and improved outcomes than parenteral opioid analgesia [23, 34].

Therefore, it would seem that thoracic epidural anesthesia (TEA)/analgesia, or other neuraxial analgesic techniques would be of particular benefit for the MO patient undergoing open abdominal or thoracic surgery; especially for those patients with OSA.

Surprisingly, only a few studies in MO patients have been published on this topic, and none have compared neuraxial anesthesia/analgesia to parenteral opioid analgesia. The lessons we have learnt using these techniques in normal weight patients must be applied when using them in the MO population.

Prior to the introduction of laparoscopic surgery, bariatric operations were performed by a traditional open, midline incision. In many bariatric centers, the usual anesthetic standard for those surgeries was, and remains, a technique combining epidural analgesia and general anesthesia [25, 26].

Rawal and colleagues found that route of administration of the same analgesic agent can have a different impact on outcomes in MO patients [2]. Epidural morphine reduced post-operative opioid requirements

with fewer opioid-related side effects (respiratory depression, nausea, and ileus) when compared to similar patients receiving IM opioids. Patients receiving epidural analgesia were also able to move, sit, and stand earlier, and had a shorter hospital stay [2].

Another modality of neuraxial anesthesia/analgesia for bariatric surgery is continuous spinal anesthesia/analgesia using local anesthetics solely or combined with opioids. Michaloudis and colleagues used isobaric 0.5% bupivacaine (1 ml every 5 min and up to 4 ml total) intrathecally during surgery [27]. For post-operative analgesia, a patient controlled intrathecal analgesia (PCIA) device (Abbott LifeCare 4200®, Abbott Laboratories, North Chicago, IL) was used. The PCIA solution was 0.05% bupivacaine and fentanyl 10 mcg ml^{-1}, and settings were: bolus dose 0.5 ml (5 mcg fentanyl + 0.25 mg bupivacaine), lock out interval 15 min, maximum total dose limits over 4 hours 120 mcg fentanyl + 6 mg bupivacaine. These authors reported that the technique was safe and provided satisfactory pain relief during the immediate post-operative period [27]. However, immediate post-operative motor block was intense and interfered with early ambulation.

In MO patients undergoing open abdominal surgery, Schumann and colleagues investigated pain intensity, analgesic consumption, patient satisfaction, and length of hospital stay resulting from different analgesic techniques [25]. In a randomized, comparative study, that included patients scheduled for open gastric bypass surgery, three different analgesic techniques were compared.

One group (Group A) had local-anesthetic-infiltration of the incision plus post-operative opioid PCA. Group B had epidural anesthesia and analgesia with local anesthetics given during surgery and a combination of meperidine 1 mg ml^{-1} and bupivacaine 0.1% infused epidurally for post-operative analgesia. Group C had post-operative PCA. Group B reported superior analgesia while in the PACU and 36 hours after surgery. Pain was the least in the epidural group, greater in Group A, and greatest in Group C. Patients in Groups A and C were significantly more likely to experience nausea in the post-operative period than those in Group B ($p < 0.05$). A greater consumption of opioids during surgery may have accounted for the increased nausea. Intra-operative systemic fentanyl administration was least in the epidural group ($p < 0.001$) [25].

Interesting conclusions can be inferred from this study. First the epidural group was treated in a unimodal manner. Second the rate of unsuccessful epidural block was high (27.8%), perhaps due to technical difficulties, a common situation in MO patients. Nevertheless, it is clear that the efficacy of epidural analgesia was superior to the other two analgesic techniques. Including neuraxial analgesia as part of a multimodal analgesic technique, and an improved success rate of epidural catheter placement, could result in improved analgesia for MO patients undergoing open abdominal surgery.

In another study, Buckley and colleagues observed that MO patients who had TEA required less volatile anesthesia and experienced less frequent post-operative respiratory complications than those who had general anesthesia with IV opioid analgesics [28]. These findings confirm the results of a meta-analysis which examined the efficacy of post-operative epidural analgesia [23]. Patients receiving either epidural analgesia or parenteral opioids were compared [23]. The study involved a general-surgical population without regard to BMI, but the data contains important information that can be applied to MO patients. The meta-analysis demonstrated that epidural analgesia provided better post-operative analgesia compared with parenteral opioids. On each post-operative day, epidural analgesia was more effective. For all types of surgery and pain assessments, all forms of epidural analgesia provided significantly better post-operative analgesia compared with parenteral opioid analgesia. The conclusion of the study was that epidural analgesia provides better post-operative pain control compared to parenteral opioids, regardless of analgesic agent, location of catheter placement, and type and time of pain assessment.

On the contrary, Charghi *et al*. observed that in grossly obese patients undergoing gastric-bypass surgery, PCA with IV morphine was an acceptable strategy for pain management compared to epidural analgesia [29]. The quality of pain control at rest, frequency of nausea and pruritus, time to ambulation, return of gastrointestinal function, and length of hospital stay was similar in both groups. Patients given epidural analgesia spent more time in the operating room (associated with epidural catheter insertion) and had a higher rate of wound infection [29].

This author agrees with Lang and Arraf that placing a low thoracic epidural catheter (T11-T12 level) is a formula for failure during upper abdominal surgery [30]. For upper abdominal surgery of any kind in any size patient, an epidural catheter inserted at a higher level (T6–T8) will provide more reliable analgesia. This was demonstrated more than 30 years ago when

Bromage and Fox observed that the most appropriate level for catheter insertion for open bariatric surgery is T6–T8 [41] For abdominal surgery, a mid-level TEA will provide excellent analgesia without cardiovascular or respiratory effects that could cause hypotension and interfere with ambulation.

15.4.1 Neuraxial analgesia as part of a multimodal approach

Based on new evidence of efficacy and safety specific to WLS patients, it is recommend that solutions for thoracic epidural pain management in OSA patients should be opioid-free to reduce the risk of respiratory depression. Using a multimodal approach including administration of epidural local anesthetics may allow significant reductions in opioid requirements or even eliminate their use while providing adequate analgesia.

15.5 Pre-emptive analgesia

Pre-emptive analgesia may improve the efficacy of post-operative pain relief while allowing further reductions in opioid requirements. Pre-emptive analgesia (or pre-emptive anti-nociception) refers to blocking neuronal pathways before injury (surgery) to reduce or eliminate the hyper-excitability of these pathways and pain memory during recovery.

The most effective pre-emptive analgesic regimens are those capable of limiting sensitization of the nervous system throughout the entire peri-operative period. The best results in pre-emptive analgesia techniques are achieved by using epidural catheters through which a continuous blockade of afferent nociceptive stimuli can be started before the surgical insult and maintained during the whole post-operative period [31].

15.6 Post-operative analgesia for obstructive sleep apnea and related syndromes

Obese patients with OSA appear to be much more sensitive than normal individuals to even minimal levels of sedation [32]. A combined anesthetic technique using general anesthesia and neuraxial anesthesia using local anesthetics, with or without opioids or with other drugs such as epinephrine or clonidine, will significantly reduce or avoid the need for parenteral opioids during surgery. These patients demonstrate an increased tendency to airway obstruction that can occur out of proportion to the level of sedation the opioids achieve [33].

Apneic episodes can occur following opioid administration by any route. Deaths have been reported in patients with OSA after minimal doses of anesthetics or sedatives due to a "tipping off" alteration in airway tone caused by airway obstruction [34].

All MO patients, regardless of whether or not they have been diagnosed with OSA, can experience frequent post-operative oxygen desaturation periods. Therefore, it is especially important that post-operative pain management does not lead to obstruction of the airway or compromise respiratory drive [35].

Practice Guidelines for the Peri-operative Management of Patients with OSA have been developed by the American Society of Anesthesiologists [36]. These Guidelines are intended to improve peri-operative care and reduce the risk of adverse outcomes in patients with OSA who receive sedation, analgesia, or anesthesia. During pre-operative evaluation, the severity of the patient's OSA, the invasiveness of surgery and anesthesia, and the requirement for post-operative opioid analgesics should be taken into account when determining if a patient is at increased peri-operative risk from OSA (see OSA Scoring System, Tables 15.1, 15.2 and 15.3) [36].

The severity of OSA should be determined by a sleep study, but if such a study has not been performed, MO patients should be treated as though they have moderate sleep apnea. The presence of certain signs and/or symptoms, as reviewed elsewhere in this book, should be considered as markers of severe OSA and must be treated accordingly. These signs and symptoms include a markedly increased BMI or neck circumference, respiratory pauses, and patients who regularly fall asleep within minutes after being left unstimulated.

To estimate the peri-operative risk, an overall score (from 0 to 6) can be obtained by adding total points in the category severity of OSA (Table 15.1) , with the greater score obtained from either invasiveness of surgery and anesthesia (Table 15.2) or requirement for post-operative opioids (Table 15.3).

One point may be subtracted if a patient has been on continuous-positive-airway-pressure or non-invasive positive-pressure ventilation before surgery and will be using his or her appliance during the post-operative period.

One point should be added if a patient with mild or moderate OSA also has a resting arterial carbon dioxide tension ($PaCO_2$) > 50 mmHg (obesity hypoventilation

Table 15.1 Severity of sleep apnea (based on sleep study or clinical indicators if sleep study not available)

Severity of OSA	Point score
None	0
Mild	1
Moderate	2
Severe	3

OSA syndrome scoring system – modified from: Practice Guidelines for the Peri-operative Management of Patients with Obstructive Sleep Apnea. A Report by the American Society of Anesthesiologists Task Force on Peri-operative Management of Patients with Obstructive Sleep Apnea. Source: Ref [36].

Table 15.2 Invasiveness of surgery and anesthesia

Type of surgery and anesthesia	Point score
Superficial surgery under local or peripheral nerve block anesthesia without sedation	0
Superficial surgery with moderate sedation or general anesthesia	1
Peripheral surgery with spinal or epidural anesthesia (with no more than moderate sedation)	1
Peripheral surgery with general anesthesia	2
Airway surgery with moderate sedation	2
Major surgery, general anesthesia	3
Airway surgery, general anesthesia	3

Source: see Table 15.1 footnote.

Table 15.3 Requirement for post-operative opioids

Opioid requirements	Point score
None	0
Low-dose oral opioids	1
High-dose oral opioids, parenteral or neuraxial opioids	3

Source: see Table 15.1 footnote.

syndrome (OHS). Any MO patient with OSA undergoing open-abdominal surgery will require large doses of opioids to achieve sufficient pain control. Accordingly, the above OSA Scoring System places the majority of patients at significantly increased peri-operative risk from OSA (scores 5 or 6). Surprisingly, many of these patients are still treated with analgesic techniques mainly based on parenteral opioid administration.

For post-operative analgesia the Task Force consultants agreed on the following:

1. Regional analgesic techniques rather than systemic opioids reduce the likelihood of adverse outcomes in patients at increased peri-operative risk from OSA syndrome.
2. The exclusion of opioids from neuraxial post-operative analgesia reduces risks compared with neuraxial techniques including those using opioids.
3. The use of NSAIDS, when acceptable, reduces adverse outcomes through their opioid-sparing effect (multimodal approach).

The consultants were equivocal regarding:

1. Whether or not an opioid PCA reduces risks compared with nurse administered IM or IV opioids.
2. Whether avoiding a basal infusion of opioids in patients at increased peri-operative risk from OSA syndrome reduces the likelihood of adverse outcomes [36].

Finally, the Task Force consultants recommended the following:

1. Regional analgesic techniques should be considered to reduce or eliminate the requirement for systemic opioids in patients at increased peri-operative risk from OSA syndrome.
2. If neuraxial analgesia is planned, the potential benefits (improved analgesia, decreased need for systemic opioids) and risks (respiratory depression from rostral spread) of using an opioid or opioid–local anesthetic mixture must be considered and compared with the risks and benefits of using local anesthetic alone.
3. If PCA opioids are used, continuous background infusions should be used with extreme caution or avoided entirely.
4. Non-steroidal anti-inflammatory drugs and other possible modalities should be considered appropriate to reduce opioid requirements (multimodal approaches) [36].

Morbidly obese patients, even if they do not have OSA, may experience other types of respiratory alterations that can increase the risks of post-operative complications. Peri-operative risk is even greater in a sub-group of obese patients who develop OHS, which is characterized by chronic daytime hypoventilation and hypoxemia ($PO_2 < 65$ mm Hg) [37].

Opioids carry a significant risk of respiratory depression and the possibility of cardiorespiratory arrest in OHS patients. Thoracic epidural anesthesia/analgesia has advantages in these patients. High

thoracic epidural anesthesia/analgesia with local anesthetics improved intra-operative conditions and produced safe post-operative pain relief reducing the necessity of giving opioids in MO patients and OHS patients who underwent cardiac surgery [38].

15.7 Post-operative analgesia obesity and spirometry

The superiority of TEA in obese patients was demonstrated in an observational study of patients undergoing open gynecologic surgeries [39]. Baseline spirometric values were all within the normal range. All spirometric values decreased significantly with increasing BMI. The greatest reduction in vital capacity (VC) occurred directly after tracheal extubation, but was less in the TEA (level of catheter insertion, T7–T8) group than in the opioid group ($p < 0.001$). In obese patients, the difference in VC was significantly more pronounced than in patients of normal weight ($p < 0.001$). Recovery of spirometric values to baseline levels was significantly quicker in patients receiving TEA, particularly in obese patients. The authors concluded that TEA should be considered for obese patients undergoing midline laparotomy to improve post-operative spirometry [39].

In MO patients undergoing open gastric bypass, hemodynamic benefits were measured in patients receiving TEA (T5 level of insertion) with local anesthetics for anesthesia and analgesia [40].

In a prospective study which compared patients receiving parenteral opioid analgesia with TEA/analgesia, Gelman and colleagues observed important benefits in the epidural group receiving continuous administration of local anesthetics. A decrease in intra-pulmonary shunt was seen in patients given epidural anesthesia. Post-operatively epidural analgesia was associated with a decrease in left ventricular stroke work, systolic pressure-heart rate product, and oxygen consumption, compared with values observed when patients experienced pain. Morphine given for relief of post-operative pain in the general anesthesia/parenteral opioid analgesia group was not associated with significant changes in cardiovascular function. Gelman and colleagues concluded that continuous-epidural-analgesia in MO patients following upper abdominal surgery decreases the oxygen requirement and benefits the cardiovascular function as reflected by a decrease in left ventricular stroke work [40].

It may be surprising that more than 30 years ago while at the Royal Victoria Hospital (Montreal),

Table 15.4 Benefits of TEA vs. parenteral opioids analgesia

Improves quality of dynamic pain relief [a]
Reductions in opioid requirements and general anesthetics (and dose-related side effects) [b]
Improves post-operative respiratory function and provides better outcomes [c]
Decreases intra-pulmonary shunt (significantly higher in the MO) [d]
Decreases oxygen consumption [d]
Benefits cardiovascular function reflected by a decrease in left-ventricular stroke work [d]
Reduces ICU requirements [e]

Sources. [a]Refs: [47, 48]; [b] Refs: [26, 41, 47, 48]; [C] Refs: [24, 39, 43, 44]; [d] Refs [40]; [e] Refs [26, 41].

Bromage and Fox proclaimed the advantages of combined TEA/light general anesthesia for bariatric surgery. They noted a significant reduction of intensive care unit (ICU) requirements, time of mechanical ventilation, shortened recovery time, superb post-operative dynamic analgesia, and reduction of general anesthetics and opioid requirements [26, 41].

In summary, epidural administration of local anesthetics may be of significant benefit for obese and MO patients undergoing open abdominal surgery. When comparing TEA, solely or as part of a multimodal analgesic approach to general anesthesia/parenteral opioids analgesia, there is cumulative evidence supporting important benefits (see Table 15.4).

15.8 Conclusions

The physiologic differences and better outcomes of TEA compared to IV opioids analgesia are summarized in Table 15.5. Morbidy obese patients undergoing open bariatric surgery or any other major open abdominal surgery are at high risk of peri-operative adverse outcomes from serious co-morbidities especially those affecting the cardiovascular and respiratory systems.

Pulmonary and cardiac morbidity can prolong ICU and hospital stays, while gastrointestinal dysfunction (ileus) will affect the length of hospital stay [42]. Epidural local anesthetic administration has shown to be essential to improve pulmonary, cardiac, and gastrointestinal outcome.

In addition, the use of local anesthetics rather than opioids returns the FRC/closing capacity proportion back to pre-operative values [24, 43, 44]. This has direct implications on the duration of post-operative mechanical ventilation, because it affects the development of atelectasis, the increase in shunt fraction, hypoxemia, and the need to reintubate the trachea and

Table 15.5 Physiologic differences and better outcomes of TEA compared to IV opioids analgesia

Lower surgical stress response
Reduced sympathetic activity
Reduced peri-operative hypercoagulability
Reduced relevant thromboembolic events
Improved subcutaneous tissue oxygenation
Less cardiopulmonary depression
Improved myocardial oxygenation
Improved post-operative respiratory function
Improved post-operative pain control
Decreased general anesthetics consumption
Decreased opioid consumption and related adverse effects
Shorter duration of ileus
Less post-operative nausea and vomiting
Shorter PACU length of stay
Shorter hospital length of stay
Increased overall patient satisfaction
In some populations, significantly lower morbidity and mortality

PACU, post anasthesia care unit.

ventilate patients. Likewise, the incidence of pulmonary infections is proportional to the length of tracheal intubation and mechanical ventilation [42].

Epidurally administered local anesthetics appear to produce their beneficial effects in pulmonary outcome by promoting post-operative recovery of diaphragmatic contractility [45, 46].

Due to special patho-physiologic conditions usually present in the MO, TEA might be even more beneficial to MO patients than to lean individuals. These conditions can be summarized as follows:

- High prevalence of OSA syndrome and OHS
- High propensity to develop apnea with the use of opioids and sedatives
- Impaired respiratory physiology (including diaphragmatic function)
- High prevalence of deep venous thromboses with or without pulmonary embolism.

In summary, after laparoscopic procedures wound infiltration with local anesthetics and low dose opioid administration by PCA or oral analgesics (when tolerated) will result in acceptable post-operative pain control. However, for patients undergoing major open abdominal procedures cumulative data shows that neuraxial analgesia provokes physiologic changes that may be implied in better outcomes observed when compared to intravenous opioid analgesia.

References

1. Schauer PR, Sirinek KR. The laparoscopic approach reduces the endocrine response to elective cholecystectomy. *Am Surg* 1995; 61: 106–11.
2. Rawal N, Sjostrand U, Christoffersson E, Dahlstrom B, Arvill A, Rydman H. Comparison of intramuscular and epidural morphine for postoperative analgesia in the grossly obese: influence on postoperative ambulation and pulmonary function. *Anesth Analg* 1984; **63**: 583–92.
3. Cancer pain and palliative care. Report of a WHO expert committee. Technical report series no. 804. Geneva: World Health Organization1990.
4. Cheymol G. Clinical pharmacokinetics of drugs in obesity. *An update*. *Clin Pharmacokinet* 1993; **25**: 103–14.
5. Oberg B, Poulsen TD. Obesity: an anaesthetic challenge. *Acta Anaesthesiol Scand* 1996; **40**: 191–200.
6. Sprigge JS, East DS, Fox GS, Ogilvie RI, Otton PE, Bevan DR. Meperidine infusion for postoperative analgesia in grossly obese patients. *Can Anaesth Soc J* 1982; **29**: 142–7.
7. Bennett R, Batenhorst R, Graves DA, Foster TS, Griffen WO, Wright BD. Variation in postoperative analgesic requirements in the morbidly obese following gastric bypass surgery. *Pharmacotherapy* 1982; **2**: 50–3.
8. Graves DA, Batenhorst RL, Bennett RL, Wettstein JG, Griffen WO, Wright BD, *et al*. Morphine requirements using patient-controlled analgesia: influence of diurnal variation and morbid obesity. *Clin Pharm* 1983; **2**: 49–53.
9. Choi YK, Brolin RE, Wagner BK, Chou S, Etesham S, Pollak P. Efficacy and safety of patient-controlled analgesia for morbidly obese patients following gastric bypass surgery. *Obes Surg* 2000; **10**: 154–9.
10. Kehlet H. 1993 John J. Bonica Lecture. Postoperative pain relief. A look from the other side. *Reg Anesth* 1994; **19**: 369–77.
11. Besson JM. The neurobiology of pain. *Lancet* 1999; **353**: 1610–5.
12. Carr DB, Goudas LC. Acute pain. *Lancet* 1999; **353**: 2051–8.
14. VanDercar DH, Martinez AP, De Lisser EA. Sleep apnea syndromes: a potential contraindication for patient-controlled analgesia. *Anesthesiology* 1991; **74**: 623–4.
15. Feld JM, Laurito CE, Beckerman M, Vincent J, Hoffman WE. Non-opioid analgesia improves pain relief and decreases sedation after gastric bypass surgery. *Can J Anaesth* 2003; **50**: 336–41.
16. Tufanogullari B, White PF, Peixoto MP, Kianpour D, Lacour T, Griffin J, *et al*. Dexmedetomidine infusion during laparoscopic bariatric surgery: the effect on recovery outcome variables. *Anesth Analg* 2008; **106**: 1741–8.

17. Cottam DR, Fisher B, Atkinson J, Link D, Volk P, Friesen C, *et al*. A randomized trial of bupivicaine pain pumps to eliminate the need for patient controlled analgesia pumps in primary laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2007; **17**: 595–600.
18. Nguyen NT, Furdui G, Fleming NW, Lee SJ, Goldman CD, Singh A, *et al*. Effect of heated and humidified carbon dioxide gas on core temperature and postoperative pain: a randomized trial. *Surg Endosc* 2002; **16**: 1050–4.
19. Farley DR, Greenlee SM, Larson DR, Harrington JR. Double-blind, prospective, randomized study of warmed, humidified carbon dioxide insufflation vs standard carbon dioxide for patients undergoing laparoscopic cholecystectomy. *Arch Surg* 2004; **139**: 739–43; discussion 743–4.
20. Neudecker J, Sauerland S, Neugebauer E, Bergamaschi R, Bonjer HJ, Cuschieri A, *et al*. The European Association for Endoscopic Surgery clinical practice guideline on the pneumoperitoneum for laparoscopic surgery. *Surg Endosc* 2002; **16**: 1121–43.
21. Savel RH, Balasubramanya S, Lasheen S, Gaprindashvili T, Arabov E, Fazylov RM, *et al*. Beneficial effects of humidified, warmed carbon dioxide insufflation during laparoscopic bariatric surgery: a randomized clinical trial. *Obes Surg* 2005; **15**: 64–9.
22. Sherwinter DA, Ghaznavi AM, Spinner D, Savel RH, Macura JM, Adler H. Continuous infusion of intraperitoneal bupivacaine after laparoscopic surgery: a randomized controlled trial. *Obes Surg* 2008; **18**: 1581–6.
23. Block BM, Liu SS, Rowlingson AJ, Cowan AR, Cowan JA, Jr., Wu CL. Efficacy of postoperative epidural analgesia: a meta-analysis. *JAMA* 2003; **290**: 2455–63.
24. Ballantyne JC, Carr DB, de Ferranti S, Suarez T, Lau J, Chalmers TC, *et al*. The comparative effects of postoperative analgesic therapies on pulmonary outcome: cumulative meta-analyses of randomized, controlled trials. *Anesth Analg* 1998; **86**: 598–612.
25. Schumann R, Shikora S, Weiss JM, Wurm H, Strassels S, Carr DB. A comparison of multimodal perioperative analgesia to epidural pain management after gastric bypass surgery. *Anesth Analg* 2003; **96**: 469–74.
26. Fox GS. Anaesthesia for intestinal short circuiting in the morbidly obese with reference to the pathophysiology of gross obesity. *Can Anaesth Soc J* 1975; **22**: 307–15.
27. Michaloudis D, Fraidakis O, Petrou A, Farmakalidou H, Neonaki M, Christodoulakis M, *et al*. Continuous spinal anesthesia/analgesia for perioperative management of morbidly obese patients undergoing laparotomy for gastroplastic surgery. *Obes Surg* 2000; **10**: 220–9.
28. Buckley FP, Robinson NB, Simonowitz DA, Dellinger EP. Anaesthesia in the morbidly obese. A comparison of anaesthetic and analgesic regimens for upper abdominal surgery. *Anaesthesia* 1983; **38**: 840–51.
29. Charghi R, Backman S, Christou N, Rouah F, Schricker T. Patient controlled i.v. analgesia is an acceptable pain management strategy in morbidly obese patients undergoing gastric bypass surgery. A retrospective comparison with epidural analgesia. *Can J Anaesth* 2003; **50**: 672–8.
30. Lang SA, Arraf J. Analgesia in bariatric patients following upper abdominal surgery. *Can J Anaesth* 2004; **51**: 276.
31. Katz J, Kavanagh BP, Sandler AN, Nierenberg H, Boylan JF, Friedlander M, *et al*. Preemptive analgesia. Clinical evidence of neuroplasticity contributing to postoperative pain. *Anesthesiology* 1992; **77**: 439–46.
32. Boushra NN. Anaesthetic management of patients with sleep apnoea syndrome. *Can J Anaesth* 1996; **43**: 599–616.
33. Esclamado RM, Glenn MG, McCulloch TM, Cummings CW. Perioperative complications and risk factors in the surgical treatment of obstructive sleep apnea syndrome. *Laryngoscope* 1989; **99**: 1125–9.
34. Young T, Peppard PE, Gottlieb DJ. Epidemiology of obstructive sleep apnea: a population health perspective. *Am J Respir Crit Care Med* 2002; **165**: 1217–39.
35. Ahmad S, Nagle A, McCarthy RJ, Fitzgerald PC, Sullivan JT, Prystowsky J. Postoperative hypoxemia in morbidly obese patients with and without obstructive sleep apnea undergoing laparoscopic bariatric surgery. *Anesth Analg* 2008; **107**: 138–43.
36. Gross JB, Bachenberg KL, Benumof JL, Caplan RA, Connis RT, Cote CJ, *et al*. Practice guidelines for the perioperative management of patients with obstructive sleep apnea: a report by the American Society of Anesthesiologists Task Force on Perioperative Management of patients with obstructive sleep apnea. *Anesthesiology* 2006 May; **104**: 1081–93.
37. Kessler R, Chaouat A, Schinkewitch P, Faller M, Casel S, Krieger J, *et al*. The obesity-hypoventilation syndrome revisited: a prospective study of 34 consecutive cases. *Chest* 2001; **120**: 369–76.
38. Berridge JC, Morgan P, Al Kalid M. High thoracic epidurac and remifentanil for anaesthesia for cardiac surgery in morbidly obese patients with obese hypoventilation syndrome. *Crit Care* 2000; 4 (suppl C): 5.
39. von Ungern-Sternberg BS, Regli A, Reber A, Schneider MC. Effect of obesity and thoracic epidural analgesia on perioperative spirometry. *Br J Anaesth* 2005 Jan; **94**: 121–7.
40. Gelman S, Laws HL, Potzick J, Strong S, Smith L, Erdemir H. Thoracic epidural vs balanced anesthesia in morbid obesity: an intraoperative and

postoperative hemodynamic study. *Anesth Analg* 1980; **59**: 902–8.

41. Bromage PR, Fox GS. Letter: Obesity: its relation to anaesthesia. *Anaesthesia* 1976; **31**: 557–9.
42. de Leon-Casasola OA. When it comes to outcome, we need to define what a perioperative epidural technique is. *Anesth Analg* 2003; **96**: 315–8.
43. Craig DB. Postoperative recovery of pulmonary function. *Anesth Analg* 1981; **60**: 46–52.
44. Wahba WM, Don HF, Craig DB. Post-operative epidural analgesia: effects on lung volumes. *Can Anaesth Soc J* 1975; **22**: 519–27.
45. Manikian B, Cantineau JP, Bertrand M, Kieffer E, Sartene R, Viars P. Improvement of diaphragmatic function by a thoracic extradural block after upper abdominal surgery. *Anesthesiology* 1988; **68**: 379–86.
46. Pansard JL, Mankikian B, Bertrand M, Kieffer E, Clergue F, Viars P. Effects of thoracic extradural block on diaphragmatic electrical activity and contractility after upper abdominal surgery. *Anesthesiology* 1993; **78**: 63–71.
47. Kehlet H, Werner M, Perkins F. Balanced analgesia: what is it and what are its advantages in postoperative pain? *Drugs* 1999; **58**: 793–7.
48. Wheatley RG, Schug SA, Watson D. Safety and efficacy of postoperative epidural analgesia. *Br J Anaesth* 2001; **87**: 47–61.

Chapter 16

Post-anesthesia care unit: Management of anesthetic and surgical complications

Stephanie B. Jones, Roman Schumann and Daniel B. Jones

16.1 Introduction

There is no question that the immediate post-operative period can be fraught with peril for the obese patient [1]. Post-surgical complications can range from the relatively commonplace (nausea and vomiting) to the potentially catastrophic (respiratory failure, acute hemorrhage, anastomotic leak). Anesthesiologists, surgeons, and post anesthesia care unit (PACU) personnel need to be aware of the unique risks for this population. Much insight into the specific peri-operative risks for severely obese patients has been gained from experience with the bariatric surgical population over the past 10 years. Data from a New York State bariatric surgery database from 1991 to 2003 demonstrated a clear difference in outcomes following primarily Roux-en-Y gastric bypass (RYGB) at low volume (< 50 cases per year) versus high volume (> 125 cases per year) centers [2]. For example, 1.8% of patients at low volume centers required post-operative re-intubation, compared to 0.7% at high volume centers; post-operative anastomotic complications occurred in 12.4% of patients at low volume centers versus 7.3% in high volume centers. These differences imply that experience of the entire care team, not just physician expertise, is important. Early recognition of complications is critical to decrease morbidity and mortality. Education on the peri-operative care of the obese patient must be frequently reinforced, and communication at hand-off points (operating room to PACU, PACU to ward) must be systematic and complete. Care pathways may guide routine management, and protocols for critical clinical milestones may identify the need to initiate a rapid response.

16.2 Nausea and vomiting

MO patients in general, and bariatric surgery patients in particular, have multiple risk factors for post-operative nausea and vomiting (PONV). The majority of weight loss surgery patients are female, intra-abdominal procedures are increasingly performed laparoscopically, and opioids are utilized for pain management. Their obese body habitus further contributes to longer duration surgery. Coexisting diabetes may result in delayed gastric emptying due to gastroparesis. Patients are often aware of the peri-operative risks of morbid obesity thanks to the internet and other media, and this may contribute to a heightened level of pre-operative anxiety. This combination of risk factors place the bariatric patient at high risk of PONV, possibly greater than 70% [3]. Consequently, anti-emetic prophylaxis is highly recommended.

Combination therapy targeting the multiple receptor systems responsible for nausea and vomiting is the most efficacious strategy [4]. Commonly utilized agents are 5-HT3 antagonists (e.g., ondansetron) in combination with dexamethasone and/or a butyrophenone such as haloperidol. 5HT-3 antagonists and dexamethasone are non-sedating, an additional benefit in a patient population at high risk for obstructive sleep apnea and post-operative hypoxemia [5]. Additional strategies may be employed to reduce the overall risk of PONV. These include minimizing the use of opioids in a multimodal post-operative pain management concept by utilizing non-opioid adjuncts such as ketorolac or alpha-2 agonists (clonidine, dexmedetomidine), and avoidance of nitrous oxide [6].

Variable data exists regarding influence of intra-operative hydration, although it can essentially be summarized as adequate hydration is important in preventing nausea, whereas excessive fluid administration may exacerbate PONV. Increased intra-operative inspired oxygen concentration had previously been proposed as another preventive maneuver, but has not been verified in subsequent trials [7]. Complementary therapies such as stimulation of the P6 acupressure point have also been advocated. In select patients with a previous history

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of severe PONV, consideration may be given towards avoiding inhalational anesthetic agents altogether and choosing a total intravenous anesthetic technique with propofol [8].

If PONV still occurs despite intra-operative prophylaxis, prompt rescue therapy is indicated, particularly following intra-abdominal surgery. Repeated patient retching stresses the surgeon who envisions tension on anastomotic suture lines of the RYNGB or gastric sleeve or prolapse of the stomach through a gastric band. Repeated doses of already administered anti-emetics may be less effective than adding a new medication that functions at a different receptor site.

16.3 Airway and respiratory complications

The American Society of Anesthesiologists (ASA) Closed Claims project maintains a database of anesthetic mishaps and periodically publishes reports detailing injury patterns and strategies for prevention. One such report described the change in death and brain damage claims secondary to difficult airway management before and after the introduction of the ASA Difficult Airway Algorithm [9]. The authors described a significant decrease in claims from events during the induction of anesthesia, but were unable to demonstrate change during other phases of peri-operative care, including recovery. Although these findings were not limited to the obese population, the data certainly imply that further attention needs to be paid to anesthesia and pain management as they pertain to airway complications in the post-operative period.

There is a high degree of association between obesity and obstructive sleep apnea (OSA), perhaps as high as 90% in a bariatric surgery population [10]. Many OSA patients are undiagnosed until screened for bariatric surgery. The PACU milieu of residual anesthetic agents and other medications, including muscle relaxants, opioid analgesics, and sedating anti-emetics, puts the MO patient, especially one with OSA, at increased risk of post-operative hypoxemia and airway obstruction [5]. Indeed, the ASA Closed Claims project related to difficult airway management showed obesity as a factor in 37% of claims related to induction of anesthesia, and in 67% of claims involving problems during airway extubation. In 28% of extubation claims, a diagnosis of OSA was present [8]. The majority of extubation or anesthetic recovery claims were associated with difficult intubation on induction, obesity and/or OSA. For this reason, many institutions have implemented "Sleep Apnea" protocols to identify and manage all patients at risk of airway compromise no matter what operation is planned.

The first line of prevention is optimization of the anesthetic regimen. Neuromuscular blockade should be fully reversed, especially given that the oropharyngeal musculature is particularly sensitive to the effects of residual paralysis [11, 12]. Opioid-sparing, multimodal pain strategies should be employed when feasible (see Chapter 15). This includes the use of local anesthetic infiltration to the surgical site, regional anesthesia techniques, non-steroidal anti-inflammatory drugs (NSAIDs), and alpha-2 agonists. If neuraxial anesthesia and analgesia is chosen, the risks and benefits of neuraxial opioid use should be carefully weighed in patients with documented sleep disordered breathing [13].

The patient should be fully awake prior to airway extubation. Some anesthesiologists prefer to use shorter acting (i.e., less lipid soluble) inhaled agents (sevoflurane and desflurane) [14]. The effects of residual inhalation agent can be avoided completely with the use of a propofol-based intravenous anesthetic for all or part of the surgical procedure. Placing the patient in a head-up (non-supine) position assists with respiratory function as well [1]. An extra set of hands can be helpful, and ideally a member of the surgical team should be readily available to perform a surgical airway. Nurses should have extra long tracheostomy sets available.

Even in the absence of airway obstruction, pulmonary function can be expected to decrease relative to baseline in the post-operative period. Open abdominal procedures impair functional residual capacity (FRC) and forced expiratory volume in one second (FEV_1) to a greater degree than laparoscopic procedures [15], and upper abdominal operations cause a further decline compared to lower abdominal or pelvic procedures. MO patients present with a restrictive pulmonary physiology, and FRC may often be less than closing capacity following surgery, predisposing to hypoxemia (see Chapter 2). Abdominal wall binders applied to offer post-operative wound support may further worsen the restrictive ventilatory defect.

The use of continuous positive airway pressure (CPAP) for early treatment of post-operative hypoxia in normal weight patients has been shown to decrease the incidence of tracheal re-intubation, pneumonia, infection, and sepsis, and to reduce intensive care unit (ICU) length of stay [16]. Anecdotal evidence that

CPAP should not be used following gastrointestinal surgery due to a potential increased risk of anastomotic leak has been largely discredited. Huerta *et al.* showed no correlation between leak rate and CPAP use following RYGB [17]. In the Bariatric Program at Beth Israel Deaconess Medical Center, Boston, USA, patients at risk for sleep apnea undergo a formal sleep study and if diagnosed with OSA they are fitted for and started on CPAP treatment pre-operatively. At the time of operation patients are instructed to bring in their own CPAP machine to the hospital for better comfort and peri-operative compliance.

The necessary length and intensity of post-operative monitoring, specifically to ameliorate pulmonary and airway risk, is a topic of extensive debate but little data. Guidelines do exist, such as the ASA's Standards for Postanesthesia Care and Practice Guidelines for the Peri-operative Management of Patients with Obstructive Sleep Apnea [13, 18]. The post anesthesia care standards specifically mention pulse oximetry as a means for assessing oxygenation. The supplemental oxygen that is commonly and appropriately administered in the PACU will slow the rate of oxygen saturation decline in the face of airway obstruction or other respiratory events, perhaps delaying recognition of an obstructive episode. Pulse oximetry, or any monitor, does not prevent morbidity if the monitor is left unattended. Pulse oximetry is not a substitute for visual monitoring by qualified caregivers, especially in the immediate post-operative period. This is clearly reflected in the ASA OSA guidelines, which recommend that continuous monitoring "be maintained as long as patients remain at increased risk" of airway obstruction or respiratory depression [13].

Helling *et al.* retrospectively reviewed their series of bariatric surgical patients [19]. Multivariate analysis associated the need for ICU care and mechanical ventilation for greater than 24 hours with BMI > 60 kg m^{-2} and need for re-operation. Male gender and age > 50 years may also be associated with a greater need for critical care resources. At Beth Israel Deaconess Medical Center, hospital guidelines recommend that patients remain overnight in a monitored setting (PACU or ICU) following a general anesthetic if they have severe OSA or a BMI > 50 kg m^{-2}. These are arbitrary thresholds with little evidence in the medical literature to support them, but they do provide general guidance for the surgical and nursing teams. Guidelines are up-dated as new data emerge.

16.4 Pulmonary embolism

Shortness of breath may be a symptom of a pulmonary embolism (PE), especially in the overweight, non-ambulatory patient. Pulmonary embolism is the most common cause of death in the bariatric surgery population despite occurring relatively rarely, with an incidence of < 1%. An Italian national registry of bariatric surgery attributes 38% of post-operative deaths to PE [20]. Carmody *et al.* recorded an incidence of PE of 0.85% in a population of over 3800 patients from a single institution over 24 years, of which 27% were fatal [21]. For patients who suffered a PE, BMI was greater on average, and even greater in those in whom the PE was fatal (65.6 kg m^{-2} vs. 54.5 kg m^{-2}). One third of the PEs in this study occurred following hospital discharge. Although a rare event, one that often occurs after discharge from the PACU, PE must nonetheless be considered in the differential diagnosis when hypoxia, tachypnea, chest pain, and/or a new arrhythmia occur in the immediate post-operative period. Interestingly, Carmody *et al.* reported no decrease in PE incidence following introduction of routine heparin prophylaxis [21]. Proper dosing requirements for heparin, as with many other medications including peri-operative antibiotic prophylaxis, are still elusive in this patient population [22]. In addition, the relative number of procedures performed laparoscopically likely also increased during the period of time of Carmody's study. It is conceivable that the advent of laparoscopy with the effects of pneumoperitoneum on venous flow conferred extra risk of venous thromboembolism (DVT) that negated the benefits of DVT prophylaxis.

Although placement of an inferior vena cava filter does not completely prevent PE, filter insertion should be considered for those at highest risk. These include the super-obese (BMI > 55 kg m^{-2}), patients with limited mobility, patients with exisiting venous stasis disease, a history of DVT, or obesity hypoventilation syndrome [23, 24]. Pre-operative consultation by a vascular surgeon is advisable, and longer duration of post-operative anticoagulation should be considered in high risk patients.

16.5 Neuropathy

The severely obese patient is at an increased risk of peri-operative peripheral neuropathy [25]. Many of these neuropathic conditions arise weeks to months after surgery, and are frequently secondary to micronutrient deficiency (see Chapters 19 and 20.)

Unilateral mononeuropathies or plexopathies may present during the recovery period. The risk of ulnar neuropathy correlates directly with increasing BMI [26], and unfortunately does not appear to be prevented by extra padding or other precautions. The brachial plexus may be injured by excessive abduction of the arm. This may happen if an improperly secured arm slips off the armrest during surgery, as frequent position changes are often necessary during laparoscopic procedures. In the severely obese, the armrest may not be level with the shoulder due to body morphology or the ramped position created to optimize intubation, and both can subsequently lead to brachial plexus stretch and injury. Readjustment of patient positioning following airway management may prevent nerve impairment in some cases.

Lateral femoral cutaneous nerve palsy (meralgia paresthetica) is the most common obesity related neuropathy in the immediate post-operative period, with a reported incidence of 0.5–1.4% [27, 28]. Some have proposed abdominal retractor positioning as the etiology, others prolonged side tilt of the operating room table with a belt securing the patient. Neither cause appears to explain every case. The size of the patient relative to the operating room table may contribute to neurologic sequelae. A leg falling sideways off the OR table, as may occur in a patient with wider girth, can injure the sciatic nerve. Even taking extra care to secure the patient can potentially backfire. For example, the use of a footboard to help ensure patient security in steep reverse Trendelenberg position can stretch the peroneal nerve. Despite careful padding and positioning, nerve injuries may still occur, but fortunately the majority will resolve over time. Neurologic consultation should be sought when neuropathic symptoms are identified.

16.6 Anastomotic leak

Almost every time gastrointestinal anastomotic leak is mentioned in the bariatric surgery literature the word "dreaded" is used to describe this complication. Leaks may have a non-specific presentation and can result in a high degree of morbidity and mortality. The overall incidence of symptomatic leak following RYGB is approximately 2–5%, primarily at the gastrojejunal (GJ) anastomosis [29, 30]. A leak typically presents with tachycardia (heart rate > 120 bpm) and respiratory distress. Fever and abdominal pain may also be present, and abdominal examination in a MO patient can be difficult. In the PACU pain can certainly be responsible for tachycardia, but persistently elevated heart rate after adequate analgesic treatment requires further exploration.

If the patient has a surgical drain in the left upper quadrant, a methylene blue test may detect a leak at the gastrojejunostomy. The awake patient is asked to drink 60 ml saline with dye and the color of abdominal drainage is monitored. Upper gastrointestinal contrast studies (UGI) may not detect all leaks (only two of nine in one series) [31, 32]. Barium swallow studies that would frequently identify a leak at the GJ may not be sensitive enough to detect a leak at the jejunojejunostomy or gastric remnant staple line. While an abdominal CT scan may be useful after a negative UGI, if tachycardia persists or symptoms worsen to include other signs such as decreasing urine output or increasing base deficit on blood gas analysis, prompt surgical re-exploration can be lifesaving [33].

Anastomotic leak has a significant effect on overall mortality following RYGB. Almahmeed *et al*. prospectively followed 840 RYGB patients, of which 36 (4.3%) presented with anastomotic leak [34]. Those with a leak had a mortality rate of 14%, compared to 4% in the no-leak group. In addition the incidence of significant morbidity including sepsis and PE increased in the leak group, resulting in a significantly increased hospital length of stay (24.5 vs. 4.5 days). As a general rule, tachycardia and respiratory compromise should alert the surgeon to a possible leak and need for re-exploration as a PE occurs less frequently. For the recovery room care team a defined threshold for early intervention with additional venous access and invasive monitoring may improve outcomes.

Anastomotic leak in the PACU should occur very rarely if time is taken intra-operatively to carefully inspect all suture and staple lines. Direct visualization, saline dye studies, air insufflation, and endoscopic visualization should exclude a leak. Technical failure and perforations should be rare. Delayed leaks after discharge from the PACU may result from suture line tension, infection, or ischemia.

16.7 Acute hemorrhage

Acute abdominal hemorrhage following intestinal, and specifically bariatric surgery, can essentially be localized to either an intraluminal or intraperitoneal source [29, 35, 36]. Podnos *et al.*, in a meta-analysis of over 3400 laparoscopic and 2700 open gastric bypass procedures found an incidence of bleeding of 1.9% for the laparoscopic cases and 0.6% for open operations [29].

Early recognition of an acute bleed can be lifesaving. Signs of hemorrhagic shock, including decreased urinary output and a narrow pulse pressure, may be overlooked. Tachycardia may be mistakenly attributed to pain or masked by peri-operative beta blockade. Bloody drainage from an abdominal drain is common although lack of output due to clot can be misleading. In the younger MO patient who is better able to compensate physiologically for hypovolemia, hypotension may be a late sign. Therefore, it is critical that the surgeon check all cut surfaces and staple lines intra-operatively.

All patients should have appropriate intravenous access and blood should be typed and crossed if hemorrhage is suspected. Post-operatively, patients routinely receive anticoagulation for DVT prophylaxis. Occasionally, continuation of aspirin in the peri-operative period may be necessary due to cardiac stents. As patients rewarm in the PACU, vessels may dilate and start to bleed. The PACU team needs to be vigilant about tachycardia, decreased urine output, hypotension, and, if drains are used, bloody output. The hematocrit can be checked and rechecked, and if a significant drop occurs, the patient should be surgically explored. More commonly the patient is asymptomatic, but there is a slow decline in hematocrit and the surgeon is unsure whether this is from bleeding or hemodilution from intravenous fluid administration. This will usually resolve with time and conservative management. Brisk bleeding from the mouth suggests a gastric staple line bleed which, if detected early, may be endoscopically clipped in the operating room, avoiding laparotomy [37]. Rectal bleeding can be an ominous sign of a large bleed requiring an emergency return trip to the operating room.

16.8 Rhabdomyolysis

A complication that is now recognized as relatively common following prolonged surgery in MO patients (7–21%) is rhabdomyolysis. This subject is discussed in detail in Chapter 18.

16.9 Conclusion

The number of obese patients undergoing major and minor surgical procedures can only be expected to increase given current population trends. These patients pose a special challenge for the PACU management team. Anesthesiologists, surgeons and nurses should conduct and participate in ongoing education about the peri-operative implications of severe obesity and relevant post-operative complications. Protocols can foster best practices and triggers can be implemented to alert the entire peri-operative team.

References

1. Schumann R, Jones SB, Ortiz VE, *et al*. Best practice recommendations for anesthetic perioperative care and pain management in weight loss surgery. *Obes Res* 2005; **13**: 254–66.
2. Parker M, Loewen M, Sullivan T, Yatco E, Cerabona T, Savino JA, Kaul A. Predictors of outcome after obesity surgery in New York state from 1991 to 2003. *Surg Endosc* 2007; **21**: 1482–6.
3. Apfel CC, Läärä E, Koivuranta M, Greim CA, Roewer N. A simplified risk score for predicting postoperative nausea and vomiting: conclusions from cross-validations between two centers. *Anesthesiology* 1999; **91**: 693–700.
4. White PF. Prevention of postoperative nausea and vomiting – a multimodal solution to a persistent problem. *N Engl J Med* 2004: **350**: 2511–2.
5. Ahmad S, Nagle A, McCarthy RJ, Fitzgeral PC, Sullivan JT, Prystowsky J. Postoperative hypoxemia in morbidly obese patients with and without obstructive sleep apnea undergoing laparoscopic bariatric surgery. *Anesth Analg* 2008; **107**: 138–43.
6. Tufanogullari B, White PF, Peixoto MP, *et al*. Dexmedetomidine infusion during laparoscopic bariatric surgery: the effect on recovery outcome variables. *Anesth Analg* 2008; **106**: 1741–1748.
7. Orhan-Sungar M, Kranke P, Sessler D, Apfel CC. Does supplemental oxygen reduce postoperative nausea and vomiting? A meta-analysis of randomized controlled trials. *Anesth Analg* 2008; **106**: 1733–8.
8. White PF, Issioui T, Hu J, *et al*. Comparative efficacy of acustimulation (ReliefBand) versus ondansetron (Zofran) in combination with droperidol for preventing nausea and vomiting. *Anesthesiology* 2002; **97**: 1075–81.
9. Peterson GN, Domino KB, Caplan RA, *et al*. Management of the difficult airway. A closed claims analysis. *Anesthesiology* 2005; **103**: 33–9.
10. Hallowell PT, Stellato TA, Schuster M, *et al*. Potentially life-threatening sleep apnea is unrecognized without aggressive evaluation. *Am J Surg* 2007; **193**: 364–367.
11. Berg H, Roed J, Viby-Mogensen J, Mortensen CR, Engbaek J, Skovgaard LT, Krintel JJ. Residual neuromuscular block is a risk factor for postoperative pulmonary complications. A prospective, randomised, and blinded study of postoperative pulmonary complications after atracurium, vecuronium and pancuronium. *Acta Anaesthesiol Scand* 1997; **41**: 1095–103.
12. Sundman E, Witt H, Olsson R, Ekberg O, Kuylenstierna R, Eriksson LI. The incidence and mechanisms of pharyngeal and upper esophageal dysfunction in partially paralyzed

humans: pharyngeal videoradiography and simultaneous manometry after atracurium. *Anesthesiology* 2000; **92**: 977–84.

13. ASA practice guidelines for the perioperative management of patients with obstructive sleep apnea. *Anesthesiology* 2006; **104**: 1081–93.
14. Arain SR, Barth CD, Shankar H, Ebert TJ. Choice of volatile anesthetic for the morbidly obese patient: sevoflurane or desflurane. *J Clin Anesth* 2005; **17**: 413–19.
15. Nguyen NT, Lee SL, Goldman C, Fleming N, Arango A, McFall R, Wolfe BM. Comparison of pulmonary function and postoperative pain after laparoscopic versus open gastric bypass: a randomized trial. *J Am Coll Surg* 2001; **192**: 469–76.
16. Squadrone V, Coha M, Cerutti E, *et al*. Continuous positive airway pressure for treatment of postoperative hypoxemia. A randomized controlled trial. *JAMA* 2005; **293**: 589–95.
17. Huerta S, DeShields S, Shpiner M, *et al*. Safety and efficacy of postoperative continuous positive airway pressure to prevent pulmonary complications after Roux-en-Y gastric bypass. *J Gastrointest Surg* 2002; **6**: 354–8.
18. American Society of Anesthesiologists Task Force on Postanesthetic Care. Practice guidelines for postanesthetic care. *Anesthesiology* 2002; **96**: 742–52.
19. Helling TS, Willoughby TL, Maxfield DM, Ryan P. Determinants of the need for intensive care and prolonged mechanical ventilation in patients undergoing bariatric surgery. *Obes Surg* 2004; **14**: 1036–41.
20. Morino M, Toppino M, Forestieri P, Angrisani L, Allaix ME, Scopinaro N. Mortality after bariatric surgery: analysis of 13,871 morbidly obese patients from a national registry. *Ann Surg* 2007; **246**: 1002–7.
21. Carmody BJ, Sugerman HJ, Kellum JM, *et al*. Pulmonary embolism complicating bariatric surgery: detailed analysis of a single institution's 24-year experience. *J Am Coll Surg* 2006; **203**: 831–7.
22. Edmiston CE, Krepel C, Kelly H, *et al*. Perioperative antibiotic prophylaxis in the gastric bypass patient: do we achieve therapeutic levels? *Surgery* 2004; **136**: 738–47.
23. Sapala JA, Wood MH, Schuhknecht MP, Sapala MA. Fatal pulmonary embolism after bariatric operations for morbid obesity: a 24-year retrospective analysis. *Obes Surg* 2003; **13**: 819–25.
24. Gargiulo NJ III, Veith FJ, Lipsitz EC, *et al*. Experience with inferior vena cava filter placement in patients undergoing open gastric bypass procedures. *Vasc Surg* 2006; **44**: 1301–5.
25. Thaisetthawatkul P, Collazo-Clavell ML, Sarr MG, Norell JE, Dyck PJB. A controlled study of peripheral neuropathy after bariatric surgery. *Neurology* 2004; **63**; 1462–70.
26. Warner MA, Warner ME, Martin JT : Ulnar neuropathy: Incidence, outcome, and risk factors in sedated or anesthetized patients. *Anesthesiology* 1994; **81**: 1332–40.
27. Koffman BM, Greenfield LJ, Ali II, Pirzada NA. Neurologic complications after surgery for obesity. *Muscle Nerve* 2006; **33**: 166–76.
28. Macgregor AM, Thoburn EK. Meralgia paresthetica following bariatric surgery. *Obes Surg* 1999; **9**: 364–8.
29. Podnos YD, Jimenez JC, Wilson SE, Stevens CM, Nguyen NT. Complications after laparoscopic gastric bypass: a review of 3464 cases. *Arch Surg* 2003; **138**: 957–61.
30. Gonzalez R, Nelson LG, Gallagher SF, Murr MM. Anastomotic leaks after laparoscopic gastric bypass. *Obes Surg* 2004; **14**: 1299–307.
31. Hamilton EC, Sims TL, Hamilton TT, Mullican MA, Jones DB, Provost DA. Clinical predictors of leak after laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Surg Endosc* 2003; **17**: 679–84.
32. Madan AK, Stoecklein HH, Ternovits CA, Tichansky DS, Phillips JC. Predictive value of upper gastrointestinal studies versus clinical signs for gastrointestinal leaks after laparoscopic gastric bypass. *Surg Endosc* 2007; **21**: 194–6.
33. Lee S, Carmody B, Wolfe L, Demaria E, Kellum JM, Sugerman H, Maher JW. Effect of location and speed of diagnosis on anastomotic leak outcomes in 3828 gastric bypass cases. *J Gastrointest Surg* 2007; **11**: 708–13.
34. Almahmeed T, Gonzalez R, Nelson LG, Haines K, Gallagher SF, Murr MM. Morbidity of anastomotic leaks in patients undergoing Roux-en-Y gastric bypass. *Arch Surg* 2007; **142**: 954–7.
35. Nguyen NT, Longoria M, Chalifoux S, Wilson SE. Gastrointestinal hemorrhage after laparoscopic gastric bypass. *Obes Surg* 2004; **14**: 1308–12.
36. Mehran A, Szomstein S, Zundel N, Rosenthal R. Management of acute bleeding after laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2003; **13**: 842–7.
37. Tang SJ, Rivas H, Tang L, Lara LF, Sreenarasimhaiah J, Rockey DC. Endoscopic hemostasis using endoclip in early gastrointestinal hemorrhage after gastric bypass surgery. *Obes Surg* 2007; **17**: 1261–7.

Chapter 17

Intensive care management of the critically ill obese patient

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17.1 Introduction

The number of obese patients admitted to intensive care units (ICUs) has paralleled the exponential growth of bariatric surgery. Recent data indicate that as many as one third of ICU patients are obese, and up to 7% are MO [1]. Furthermore, a substantial portion of bariatric surgical patients may require prolonged ICU care. Nguyen *et al.* reported that 7.6% of laparoscopic gastric bypass patients and 21.1% of open gastric bypass patients required ICU care following surgery [2]. Similarly, recent series have documented that 6–24% of bariatric surgical patients require more than 24 hours of ICU care [3, 4, 5]. Obese patients have physiologic derangements due to higher metabolic requirements, stressing multiple organ systems (Table 17.1). The post-operative care of MO patients must be therefore modified and tailored to optimize their ICU and hospital course.

17.2 Pathophysiology and management

17.2.1 Cardiovascular aspects

The obese state is an independent risk factor for coronary artery disease, apart from the increased prevalence of hypertension, hypercholesterolemia, and type 2 diabetes mellitus associated with obesity. Due to sedentary lifestyle, symptoms of angina or congestive heart failure may not be easily elicited pre-operatively.

The pathophysiology of cardiovascular disease in obese patients is discussed in detail in Chapter 1. Circulating blood volume is increased to supply additional adipose and lean tissue. Increased blood volume increases preload, stroke volume, cardiac output, and myocardial work. Elevated circulating concentrations of catecholamines, mineralocorticoids, renin, and aldosterone increase afterload. Hyperkinesis, myocardial hypertrophy, decreased compliance, diastolic dysfunction, and, eventually, ventricular failure ensue. The diastolic dysfunction characteristic of obesity results in altered Starling mechanics characterized by a relatively narrow range of left ventricular filling pressures prior to decompensation. A pulmonary artery catheter may be useful in obese patients who require large-volume fluid resuscitation, although the value of this modality has not been proved and must be weighed against the mechanical risks of central venous access and catheter-related infection. An indwelling arterial catheter should be employed when hemodynamic stability is in question. The use of peri-operative beta-blockade in patients at risk for cardiovascular disease decreases morbidity and mortality from cardiovascular events but increases mortality from stroke. Because of the increased stroke risk and the impaired ventricular contractility due to decreased beta-adrenergic receptors beta-blockade should be used cautiously for obese patients.

Both CO_2 pneumoperitoneum and reverse Trendelenburg positioning have been implicated in impairing cardiac function during laparoscopic gastric bypass [6]. Nguyen *et al.* randomized 51 patients to receive either open or laparoscopic gastric bypass [7]. Both groups were placed in the reverse Trendelenberg position. Abdominal insufflation in the laparoscopic group resulted in increased systemic vascular resistance and decreased cardiac output compared to both baseline and the open gastric bypass group immediately after incision. Since systemic vascular resistance and cardiac output recovered within 1.5 hours and 2.5 hours, respectively, of abdominal insufflation, any adverse hemodynamics noted in the post-operative period should not be blamed on consequences of the pneumoperitoneum in the operating room.

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Table 17.1 Major organ-system pathophysiology in obesity

Organ system	Pathology
Respiratory	↓FRC, TLC, VC, IC, ERV
	↑FEV_1:FVC
	Obstructive sleep apnea syndrome
Cardiovascular	↑Blood volume
	↑Vascular tone
	↓Ventricular contractility
Renal	↑Clearance of renally-excreted drugs
	Hypertensive and diabetic nephropathy
Hematologic	↑Fibrinogen
	↑PAI-1
	↓AT-III
	Venous stasis
Gastrointestinal	Hiatal hernia
	↑Gastric secretion volume
	↓Gastric pH
Metabolic/Endocrine	↑Resting energy expenditure
	Insulin resistance
	↑Proteolysis
Immunologic	↑TNF-α
	↑IL-6
	Impaired neutrophil function

FRC, functional residual capacity; TLC, total lung capacity; VC, vital capacity; IC, inspiratory capacity; ERV, expiratory reserve volume; FEV_1:FVC, ratio of forced expiratory volume in one second to forced vital capacity; PAI-1, plasminogen activator inhibitor-1; AT-III, antithrombin-III; TNF-α, tumor necrosis factor-alpha; IL-6, interleukin-6.

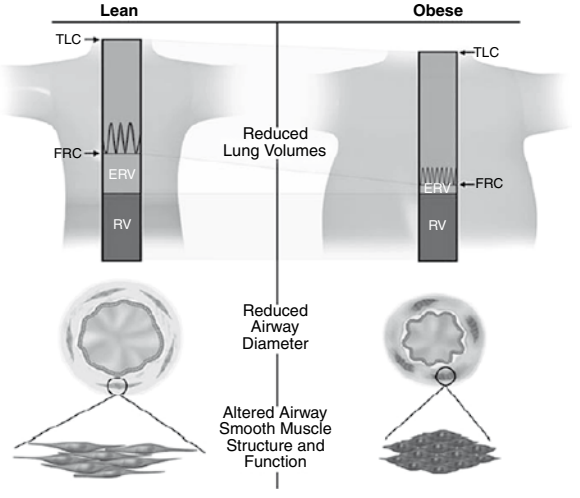

Figure 17.1 Obesity leads to alterations in lung volumes, reduced peripheral airway diameter, and alterations in smooth muscle structure and function. The combined result entails reduced lung volumes and airway hyperresponsiveness, which is exacerbated by upper airway obstruction due to increased soft tissue mass. Reproduced, with permission, from Beuther, *et al*. Obesity and asthma. *Am J Respir Crit Care Med* 2006 **174**: 112–9.

Bariatric surgery can be performed safely in patients with pre-existing cardiovascular disease [8, 9]. The significant potential for multi-organ system benefit after weight loss surgery makes the moderate risk of cardiovascular events acceptable.

17.2.2 Pulmonary aspects

Pulmonary pathophysiology associated with obesity involves both restrictive and obstructive components (see Chapter 2). Increases in both pulmonary blood volume and chest wall mass restrict lung expansion. The abnormally high diaphragm position, upper airway resistance, altered smooth muscle function, as well as an increased daily CO_2 production exacerbate respiratory load and further increase the work of breathing. The consequences of this restrictive pattern are a decreased functional residual capacity (FRC), total lung capacity, expiratory reserve volume, and minute ventilatory volume, with a compensatory baseline rapid, shallow breathing pattern (Figure 17.1). Furthermore, obesity is correlated strongly with asthma, which also often improves following bariatric surgery.

Obstructive sleep apnea (OSA) syndrome is found in 40–70% of bariatric surgical patients (see Chapter 2). Polysomnography (PSG) may be considered in the pre-operative evaluation of bariatric surgical patients. Empiric continuous positive airway pressure (CPAP) via mask (10 cm H_2O) may be instituted if patients are unable to complete PSG prior to surgery. The CPAP acts to displace the tongue and pharyngeal soft tissues, preventing airway obstruction. Although CPAP may cause gastric distention from ingested air at increased pressure, CPAP has not been found to increase the rate of anastomotic failure. Livingston *et al*. noted similar rates of anastomotic leak in gastric bypass patients receiving CPAP (2/159, 1.3%) compared to those not receiving CPAP (10/908, 1.3%) [10].

An increased incidence of hiatal hernia and increased intra-abdominal pressure secondary to large abdominal panniculus may increase the risk of aspiration in the obese population. Altered gastric pH

and fluid volume have been found in obese surgical patients [11]. In a cross-sectional study by Vaughan *et al*., 42/56 (75%) of obese patients compared to 0/50 (0%) normal weight controls shared the combination of gastric secretion volume greater than 25 ml and gastric fluid pH less than 2.5 [11], levels considered traditionally to place the adult patient at risk for aspiration pneumonitis. However, Zacchi *et al*. found normal gastroesophageal junction resistance gradients in obese patients without gastroesophageal reflux disease or hiatal hernia, and concluded that obesity alone was not a risk factor for aspiration [12]. It may be prudent to take precautions against acid aspiration in the critically ill obese patient. Histamine H_2-antagonists maintain gastric volume < 25 ml and gastric pH > 2.5 effectively in MO patients [13].

Obese patients with relatively short, thick necks and redundant oropharyngeal tissue may render elective intubation difficult. Rapid arterial desaturation is common after induction of anesthesia. A laryngeal mask airway or fiberoptic intubation under direct visualization may be helpful in cases of difficult endotracheal intubation.

The multiple physiologic changes associated with MO predispose these patients to respiratory failure in the setting of even mild pulmonary or systemic insults. Total respiratory system elasticity is significantly elevated, primarily due to decreased chest wall compliance, but also by decreased lung compliance. Total respiratory resistance is also elevated, especially in the supine position due to early distal airway closure. Greater elasticity and resistance result in disproportionately increased work of breathing with greater oxygen requirement, and may be as high as four times normal even at rest. Despite working against a less compliant chest wall and a heightened demand for diaphragmatic work, obese individuals are reportedly capable of generating lower maximum inspiratory pressures and have less respiratory muscle endurance compared to the non-obese. Thus, MO patients require early intervention for respiratory support especially in the post-operative period.

Mechanical ventilation for the obese patient with respiratory failure is particularly challenging. These patients have reduced FRC, while the total lung capacity and vital capacity are unchanged. In cases of mild obesity the forced expiratory volume in 1 s and forced vital capacity may be normal, but are likely to decline with increasing levels of obesity. The underlying mechanism of gas exchange abnormalities appears to be alveolar hypoventilation secondary to airway closure and atelectasis of the basilar airways. Consequent to these alterations, longer durations of mechanical ventilation with higher extubation failure rates have been reported.

Delivered tidal volume should be calculated based on ideal body weight (IBW) rather than total body weight (TBW) to avoid high airway pressures, alveolar over-distension, and barotrauma. End-tidal CO_2 monitors are unreliable because of widened alveolar–arterial gradients present in most obese patients. Providing an intubated, MO patient with positive end-expiratory pressure (PEEP) up to 10 cm H_2O improves lung volumes, PaO_2, $PaCO_2$, elasticity, and intra-abdominal pressure compared to non-obese controls [14]. Finally, the reverse Trendelenberg position at 45° facilitates weaning from the ventilator and tracheal extubation by improving ventilatory mechanics [15]. In critically ill obese patients, reverse Trendelenberg positioning at 45° resulted in increased PaO_2 and tidal volume, and decreased respiratory rate as compared to the supine position [15]. The combination of beach chair position and PEEP (10 cm H_2O) improved oxygenation as measured by elastance, end-expiratory lung volume, and arterial oxygen tension in MO patients undergoing laparoscopic gastric banding [16]. These strategies should be utilized to optimize oxygenation peri-operatively.

A substantial fraction of bariatric surgery patients require greater than 24 hours of mechanical ventilation post-operatively. There is no association of MO with duration of mechanical ventilation, but MO be associated with longer ICU and/or hospital stay [17]. In one series 44 of 250 (18%) consecutive bariatric surgery patients remained intubated for greater than 24 hours after surgery [18]. Prolonged respiratory failure following bariatric surgery, however, appears to be less common. Livingston *et al*. reported only 9/1067 (0.6%) cases of respiratory failure in their large series of gastric bypass patients [10]. Furthermore, using the 2002 Healthcare Cost and Utilization Project National Inpatient Sample, Poulose *et al*. documented 7.3 cases of respiratory failure per 1000 bariatric patients [19].

For patients with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS) requiring prolonged intubation, it is paramount to combine low tidal volume with high PEEP while maintaining lower inspiratory peak pressures. In a landmark study of normal weight patients with ALI or ARDS, mortality was reduced by 22% and the number of ventilator-free

days was greater in the group treated with lower tidal volumes [20]. Given that the MO patients have reduced FRC, it is especially important to follow these principles.

Effective pulmonary toilet is of crucial importance in preventing post-operative complications in the bariatric patient as splinting and atelectasis exacerbate pre-existing pathology. MO patients fare worse once pulmonary complications develop. El-Solh *et al.* reported that, compared to non-obese controls, MO patients spent significantly more time on the ventilator (10.6 days vs. 4.6 days), required more time to achieve extubation (3.2 days vs. 1.8 days), and required more oxygen throughout hospitalization (FiO_2 38.4% vs. 31.1%) [21]. A review of 24 157 post anesthesia care unit patients revealed that obese patients were more than twice as likely to suffer from a critical respiratory event defined as unanticipated hypoxemia, hypoventilation, or upper airway obstruction requiring an active intervention [22].

Patients with respiratory failure may benefit from early tracheostomy. Tracheostomy is hazardous and technically demanding in obese patients due to their anatomy. Longer tracheostomy tubes with sharper angles may be necessary to accommodate increased neck girth and tracheal depth in obese patients. Percutaneous tracheostomy remains controversial for these patients. Mansharamani *et al.* reported no complications in 13 consecutive obese patients [23], but Byhahn *et al.* reported a 2.7-fold increased risk of peri-operative complications in obese patients compared to non-obese controls (95% confidence interval [CI] 1.8–4.1), with a 4.9-fold increased risk of serious complications (95% CI 3.1–7.8) [24]. The overall complication rate of percutaneous tracheostomy for 73 obese patients was 43.8%. However, more recent studies have shown that the complication rates of tracheostomy may be lower than previously reported, and that there is no significant difference in rate of complications between open and percutaneous trachestomies. One study looking at complications of open vs. percutaneous tracheostomy in 143 patients with BMI > 35 showed similar rate of ~ 6% [25].

Early ambulation and minimal time spent in the supine position following bariatric surgery are of paramount importance. Ambulation within 2 hours of surgery and frequently thereafter is common to many post-operative bariatric protocols. Finally, respiratory decompensation following gastric bypass should always alert the clinician to the possibility of an abdominal problem such as anastomotic dehiscence.

17.2.3 Nutrition

Malnutrition and obesity are not mutually exclusive, and the supposition that "starving" obese patients during critical illness is well tolerated or even beneficial is erroneous. There are no body reserves of protein, even in corpulent patients. Obese patients have increased resting energy expenditure secondary to increased BMI, with central adipose tissue being more metabolically active than peripheral adipose tissue.

Obesity is characterized by the metabolic syndrome, which includes insulin resistance, hyperinsulinemia, hyperglycemia, coronary artery disease, hypertension, and hyperlipidemia (see Chapter 3). Elevated basal insulin concentrations in obesity suppress lipid mobilization, causing accelerated proteolysis to support gluconeogenesis, which in turn results in rapid muscle loss and early deconditioning. A case-control study of obese blunt trauma patients revealed that obese patients mobilized relatively more protein and less fat compared to non-obese controls [26]. This shift from fat to carbohydrate metabolism increases the respiratory quotient, causing hypercapnia that may impede airway extubation.

Nutrition in critically ill obese patients should supply enough glucose to spare protein. Calories should be supplied primarily as carbohydrates, with fats given to prevent essential fatty acid deficiency. Most recommended enteral feeding regimens supply 30 kCal kg^{-1} and 2.0 g kg^{-1} protein day^{-1}, based on IBW. The benefit of hypocaloric feedings in the critically ill obese patient has been investigated. Dickerson *et al.* reviewed 40 critically ill, obese surgical patients and found that those who received hypocaloric enteral feedings (< 20 kCal $kg^{-1}day^{-1}$ based on IBW) had decreased ICU length of stay, received fewer days of antibiotics, and had a decreased length of mechanical ventilation compared to those fed eucaloric feedings (20 kCal $kg^{-1}day^{-1}$) [27]. The authors postulated that improved outcome in the hypocaloric group was related to fewer complications of overfeeding. Prospective trials are warranted.

Total parenteral nutrition is used often in post-operative bariatric patients when enteral feeding is impossible. However, although data specifically addressing the bariatric patient population are not available, total parenteral nutrition has not been shown to decrease major post-operative complication rates and mortality in critically ill post-operative patients. Placement of a feeding gastrostomy tube into the bypassed gastric remnant at the time of surgery should be considered when performing revisional bariatric

surgery, or if a prolonged period of critical illness is anticipated (after surgical complications have ensued).

Glycemic control using intensive insulin therapy has been an important development in the care of the critically ill surgical patient. Intensive insulin therapy substantially prevented several critical illness-associated complications, including the development of critical illness polyneuropathy, blood stream infections, anemia, acute renal failure, and hyperbilirubinemia [28, 29]. Critically ill MO patients are more likely to require an insulin infusion and require more mean units of insulin per hour to maintain euglycemia as compared to non-MO patients. However, provided that an aggressive approach to euglycemia is employed successfully in MO patients, the risk of adverse outcomes, including nosocomial infection, is not increased [30]. Given that many of the bariatric patients have insulin-dependent diabetes, hyperglycemia should be aggressively treated in both ICU and hospital setting.

17.2.4 Adrenal insufficiency

Elevated cortisol level has been associated with increased body weight or fat mass, aging, and men, likely due to high percentage of visceral fat. Increasing body weight is associated with increasing cortisol production rate (CPR), which is balanced by enhanced cortisol clearance, resulting in daily plasma free cortisol levels that are independent of body size [31]. These data indicate that human obesity is not characterized by a dysregulation of the hypothalamic-pituitary-adrenal axis; however, its response in the critical illness setting is not well described. The benefits of early treatment of adrenal insufficiency in certain critically ill patients have been shown in a number of studies.

Critical illness-related corticosteroid insufficiency is caused by adrenal insufficiency together with tissue corticosteroid resistance. This is typically characterized by an exaggerated and protracted pro-inflammatory response associated with hemodynamic instability. Critical illness-related corticosteroid insufficiency should be suspected and treated in hypotensive patients who have responded poorly to fluids and vasopressor agents, particularly in the setting of sepsis. The diagnosis of adrenal insufficiency in critically ill patients is best made by a total serum cortisol of < 9 mcg dl^{-1} after adrenocorticotrophic hormone (250 mcg) administration or a random total cortisol of < 10 mcg dl^{-1}. The benefit of treatment with glucocorticoids at this time seems to be limited to patients with vasopressor-dependent septic shock and patients with early severe acute respiratory distress syndrome (PaO_2/FiO_2 of < 200 and within 14 days of onset). According to the concensus by the American College of Critical Care Medicine, published in 2008, this is best treated with hydrocortisone at a dose of 200 mg day^{-1} in four divided doses or as a continuous infusion at a dose of 240 mg day^{-1} (10 mg h^{-1}) for ≤ 7 days is recommended for septic shock [32]. Methylprednisolone in a dose of 1 mg × kg[−1] × day[−1] for > or = 14 days is recommended in patients with severe early acute respiratory distress syndrome. Glucocorticoids should be weaned and not stopped abruptly. For those with refractory instability, reinstitution of treatment should be considered with recurrence of signs of sepsis, hypotension, or worsening oxygenation. Early recognition and treatment of adrenal insufficiency in appropriate patients will decrease mortality rate in these critically ill patients.

17.2.5 Pharmacology

In general, metabolic clearance increases linearly with the increased lean body weight (LBW) in the MO patient, suggesting LBW is an important parameter for maintenance dosing. Also, obese patients with normal renal function have an increased glomerular filtration rate and thus an increased clearance of drugs excreted by the kidney. However, type 2 diabetes mellitus and hypertension, which complicate obesity frequently, may cause renal dysfunction. Therefore, renal function must be determined on an individual basis. Furthermore, calculated and measured creatinine clearance correlate poorly in obesity [33], mandating measurement of creatinine clearance with timed urine specimens in all obese patients with suspected renal dysfunction.

The increased ratio of adipose to lean body mass alters the volume of distribution (V_d) of drugs. Accumulation of lipophilic drugs may prolong the elimination half-life. The V_d of hydrophilic drugs may relate better to LBW or IBW because of poor penetration into adipose tissue. Dosing of hydrophilic drugs based on TBW in the obese patient population may overestimate necessary dosages, leading to toxicity. Nonetheless, blood, extracellular fluid, body organ, and connective tissue volume, to which hydrophilic drugs may distribute, are all also increased in obese patients. Thus, whereas dosing of hydophilic drugs may initially be based on LBW or IBW, serum concentrations should be monitored whenever possible to ensure therapeutic concentrations [34].

Due to variable alterations in V_d, clearance, and elimination half-life, dosing adjustments for specific drugs in obese patients can be complex. Some individual drugs used commonly in critical illness that have been studied in obese patients are discussed below.

Propofol is a hypnotic, lipophilic drug with a rapid onset and short duration of action. Both V_d and clearance of propofol are increased in obese patients and correlate with TBW. Elimination half-life is unchanged compared to non-obese controls. Dosing of propofol for induction of anesthesia should be based on LBW and dosing for a maintenance infusion for sedation may be based on TBW.

The lipophilic benzodiazepines demonstrate markedly increased V_d, similar clearance, and increased elimination half-life in obese patients. Dose calculations based on TBW will result in overdose and calculations for continuous infusion should follow IBW or LBW. Frequent interruptions in infusion with assessment of patient response are necessary to avoid delayed weaning from mechanical ventilation and prolonged ICU length of stay [36].

Fentanyl is a synthetic, lipophilic opioid with a rapid onset of action and no histamine-related vasodilation. Fentanyl administration should initially be based on LBW and thereafter carefully titrated to effect.

Although the pharmacokinetics of many antimicrobials in obese patients is unknown, several exceptions warrant discussion. Both the V_d and clearance of vancomycin correlate better with TBW than IBW in MO patients [37]. A shorter elimination half-life of vancomycin relative to non-obese patients may require shorter dosing intervals to achieve therapeutic steady-state trough concentrations (e.g., every 8 h vs. every 12 h) [37]. Due to variability in both dosage amount and dosage interval, serum concentrations of vancomycin should be monitored in obese patients [38].

Linezolid is an oxazolidinone with activity against multi-drug-resistant gram-positive bacteria. Data regarding the pharmacokinetics of linezolid in obese patients are currently limited to case series involving non-critically ill patients with cellulitis [39]. In these reports, clinical cure was achieved using the standard dosing regimen of 600 mg orally every 12 h. Data involving critically ill patients are necessary prior to formulating meaningful recommendations.

The hydrophilic aminoglycosides and fluoroquinolones require use of a pre-determined dosing weight correction factor (DWCF) to calculate dosing weight (Table 17.2). Clinical studies suggest a DWCF of approximately 0.45 for both aminoglycosides [40] and quinolones [41]. However, because a wide range of DWCF for aminoglycosides has been reported in the literature, subsequent dosing should be based on serum concentrations. Monitoring serum concentrations of aminoglycosides is of particular importance in obesity because of an increased susceptibility to nephrotoxicity. Alterations of dosage interval in obese patients with normal renal function are usually unnecessary [34]. Once-daily dosing of aminoglycosides in obese patients has not been studied and is not recommended.

The PROWESS trial of drotrecogin alpha (APC) [42] excluded patients weighing more than 135 kg. A subsequent study that included MO patients documented similar plasma concentrations and elimination half-lives of APC when dosed by TBW [43]. Therefore, APC may be used for treatment of severe sepsis in MO patients and should be dosed according to TBW without limitation of dosage. Dosing weights in obese patients for drugs used commonly in critical illness are summarized in Table 17.2.

Table 17.2 Dosing weights in obese patients for selected drugs used commonly in critical illness

Drug	Dosing weight
Propofol	
Induction dose	LBW
Continuous infusion	TBW
Benzodiazepines	
Single-dosage	TBW
Continuous infusion	IBW
Fentanyl	LBW
Vancomycin	DBW
Penicillins and cephalosporin	DW
Aminoglycosides	DW
Fluoroquinolones	DW
Macrolides	IBW
Drotrecogin alpa [activated]	TBW
Heparin	DW

TBW, total body weight; IBW, ideal body weight.; DW, drug weight.
DW: IBW + (0.40 × [TBW – IBW]).
IBW: Men = 50 kg + 2.3 kg/inch of height > 5 ft.
Women = 45.5 kg + 2.3 kg/inch of height > 5 ft.

17.3 Specific complications following bariatric surgery

17.3.1 Anastomotic leak

Anastomotic leak is a potentially very serious complication that may be difficult to diagnose in the MO patient. It is the second leading cause of mortality following gastric bypass surgery [44]. Recent case series have reported an incidence ranging from 0.5% to 2%. Bariatric patients who sustain a post-operative anastomotic leak suffer increased hospital length of stay, ICU length of stay, and mortality.

In a recent review of 210 consecutive laparoscopic Roux-en-Y gastric bypass patients, Hamilton *et al.* found severe tachycardia (HR >120 beats per minute) and respiratory failure (development of an increasing oxygen requirement after discharge from the post-anesthesia care unit, SaO_2 < 92% on room air, or respiratory rate > 24 breaths/minute) to be the two most common presenting manifestations of anastomotic leak [45]. As mentioned previously, failure of progression to airway extubation or sudden respiratory decompensation in the immediate post-operative period should thus raise suspicion of intra-abdominal pathology. Concurrent symptoms and findings, such as left shoulder pain, increasing abdominal pain, a perception of impending doom, or an isolated left pleural effusion on chest radiograph may aid in differentiating anastomotic leak from other common causes of post-operative respiratory decline, most notably pulmonary embolism (PE).

Whereas upper gastrointestinal (UGI) contrast imaging is both useful and employed routinely in diagnosing anastomotic failure, a negative study does not exclude the diagnosis; a water-soluble gastrointestinal contrast study revealed an anastomotic leak in only two of nine patients in the aforementioned study by Hamilton *et al.* [45]. A more recent study underscored the poor sensitivity of UGI imaging for detecting suspected jejunojejunostomy leaks; nine of ten leaks at this site were not detected [46]. Mortality for this group of patients was 40%. Routine UGI imaging following gastric bypass does not appear to offer any benefit over selective use. With newer CT scanners that can accommodate heavier patients, more surgeons are relying on this type of imaging to detect small, contained leaks or collections. Helical CT has been helpful in identifying the post-surgical anatomy as well as many of the complications. After gastric bypass, the pouch, remnant stomach, and anastomoses can be identified in the majority of cases. Many complications are also identified including leak, fluid collection, small bowel obstruction, hematoma, staple line dehiscence, and solid organ injury. Although the sensitivity of the helical CT in detecting complications is not well established, it is a useful diagnostic tool to be used in conjunction with clinical exam.

Clinically stable patients may undergo diagnostic tests and minimally invasive intervention. However, these patients have protean presentations and unreliable physical exam, and early recognition and treatment is key. Failure to promptly recognize an anastomotic leak can result in rapid deterioration and death, thus post-operative bariatric patients with persistent tachycardia or respiratory distress in whom PE has been ruled out should undergo exploratory laparotomy, regardless of UGI or CT imaging results.

17.3.2 Anastomotic bleed

The cause for upper gastrointestinal hemorrhage (UGH) in the early post-operative period after laparoscopic RYGB seems to be related to problems at the staple line. Early UGH is defined as GI hemorrhage occurring within 48 hours after the procedure. There are four potential sites of staple-line hemorrhage: the gastric pouch, the gastrojejunostomy, the jejunojejunostomy, and the bypassed stomach. However most reports have found that bleeding typically occurs at the gastrojejunostomy.

The incidence of early UGH after laparoscopic RYGB ranges from 1% to 4%, and it appears to be greater than that of open RYGB. The best treatment for UGH is esophagogastroduodenoscopy to first determine if there is bleeding and to then perform therapeutic intervention such as cauterization or epinephrine injection. However, performing EGD in the post-operative MO patient requires careful monitoring and pre-emptive set-up for multiple reasons. These patients may have difficult airways. Given recent surgery for small gastric pouch and fresh anastomosis, the patients are at much higher risk for aspiration and iatrogenic disruption of the anastomosis. Therefore, EGD should be performed only in the presence of an experienced anesthesiologist, preferably in the operating room. Irrespective of initial *Helicobacter pylori* status, many physicians will keep patients on proton pump inhibitors for 6 months after surgery. In patients who have undergone RYGB, many are at risk for marginal ulcers or stenosis, especially with smoking and non-steroidal

anti-inflammatory drug use. One study found that over 40% of post-RYBG patients had marginal ulcer after surgery [47]. Median time for diagnosis was 2 months and 95% of the patients presented within 12 months. Although proton pump inhibitors (PPIs) have been shown to be protective against marginal ulcer, they may not be as effective in this patient population. It should be noted that in more than 90% of patients, the pH of fluid in the small gastric pouch is at least 4, so PPIs are not generally effective for prevention or treatment of pouch gastritis or anastomotic ulcers. Sucralfate is the treatment of choice for these disorders in the setting of a near neutral or elevated pH.

17.3.3 Pulmonary embolism and deep vein thrombosis

Obese patients are believed to be at increased risk of thromboembolic complications due to increased blood viscosity, decreased concentration of AT-III, and increased concentration of both fibrinogen and PAI-1 produced by adipocytes. Sedentary lifestyle, venous stasis, and pulmonary hypertension augment this risk. Endothelial injury as a result of surgery further predisposes the obese surgical patient to thromboembolic complications. Several prospective studies have identified obesity as a risk factor for post-operative venous thromboembolism (VTE) after elective major abdominal surgery. Post-operative pain must be adequately controlled so that patients can be mobilized almost immediately after surgery. If there is any clinical suspicion such as unilateral extremity swelling or tachycardia with desaturation, diagnostic tests for DVT and/or PE must be performed immediately. The MO population has a significant risk of these complications and much lower respiratory reserve to sustain such insult.

Despite an increased risk within the obese population, the reported incidence of VTE following bariatric surgery is low. Prospective studies have reported an incidence of VTE from 0% to 2.4%, and PE from 0% to 1.2%. However, variable methods of prophylaxis were used, and the majority of patients were not critically ill. Gonzalez *et al.* identified age > 50 years, anastomotic leak, a history of smoking, and a history of VTE as independently predictive of post-operative VTE in 660 consecutive patients who underwent gastric bypass [48].

Although VTE is rare, PE is the most common cause of post-operative mortality and an independent risk factor for death following bariatric surgery. In a review of 3464 bariatric surgery patients, PE accounted for 50% of deaths [49]. Livingston *et al.* documented nine post-operative pulmonary emboli in 1067 bariatric surgery patients, of which six were fatal [10]. Multiple studies have shown similar results, confirming PE-related mortality rate of up to 50% in bariatric surgery patients.

Whereas more than 95% of obesity surgeons use some form of thromboprophylaxis routinely, no specific regimen is employed universally. Scholten *et al.* documented a low incidence of post-operative VTE with a multi-modality prophylaxis protocol including early ambulation, graded compression stockings, intermittent pneumatic compression (IPC) stockings, and enoxaparin 40 mg subcutaneously every 12 hours [50]. A recent meta-analysis recommended unfractionated heparin, low molecular weight heparin, or IPC stockings for high-risk patients undergoing elective abdominal surgery [51]. Emphasis must be placed on proper timing of prophylaxis, with the initial dose of pharmacoprophylaxis given 1–2 hours pre-operatively.

Enoxaparin has been extensively studied in this context. In a study of bariatric surgical patients, those administered 40 mg every 12 hours had a lower incidence of post-operative deep venous thrombosis compared with those receiving 30 mg twice daily. Bleeding events were no different between groups [50]. In another multicenter, retrospective trial bariatric surgical patients in whom enoxaparin was given for VTE prophylaxis at a dose of 30 mg and begun preoperatively or given 40 mg every 12 or 24 h post-operatively resulted in no reported deep venous thrombosis and a low occurrence of PEs (0–2%). Severe bleeding, largely gastrointestinal in origin, occurred in only 0.9% of the entire study population [52].

Appropriate dosing and duration of chemoprophylaxis following bariatric surgery is controversial. The incidence of VTE is actually relatively low, and sequential compression devices alone may be sufficient to prevent VTE without adding the hemorrhagic risks of chemoprophylaxis. Further study of this topic is warranted probably in a randomized fashion with a large sample size that will only be achievable by a multicenter study.

Prophylactic inferior vena cava (IVC) filter placement may be beneficial for those bariatric patients at extremely high risk for post-operative VTE. A higher incidence of VTE has been reported in super obese patients, patients with truncal obesity, venous stasis disease, or a prior history of VTE. In one study, 12 fatal PEs (0.21%) were identified in 5554 bariatric surgical patients [53]. Four co-morbidites were common

to four patients (33%): venous stasis disease, BMI ≥ 60 kg m^{-2}, truncal obesity, and obesity hypoventilation syndrome/sleep apnea syndrome. Although no randomized trials exist addressing the value of prophylactic IVC filter placement in this population, the pre-operative placement of retrievable IVC filters appears feasible for patients with one or more of these high-risk factors. These studies suggest the post-operative use of low molecular weight heparin or prophylactic retrievable IVC filter may decrease the incidence of PE related mortality in super-obese patients (BMI > 60 kg m^{-2}).

17.3.4 Early small bowel obstruction

Small bowel obstruction (SBO) within the first month of surgery has become an increasingly recognized serious complication following both laparoscopic and open gastric bypass, occurring in approximately 2% of cases. The most common causes of early SBOs are technical, involving kinking at the jejunojejunostomy, anastomotic stenosis due to tissue edema, internal hernia at the mesenteric defects, or external compression of the Roux-en-Y limb at the location of the transverse mesocolon.

Sudden and severe abdominal pain, tachycardia, nausea, vomiting, and obstipation are both the most common and most concerning symptoms reported by patients with early post-operative SBOs. Because isolated obstruction of the excluded biliopancreatic limb may occur following gastric bypass surgery, termed bypass obstruction, both gastric and intestinal ischemia and frank necrosis may occur in the absence of obstipation. Such cases of bypass obstruction portend a grave prognosis due to massive fluid and electrolyte loss into the excluded stomach, with resultant hypovolemic shock, perforation, sepsis, and death. Distention may arise from either torsion of the lengthy diverted limb or adynamic ileus. Nasogastric tube decompression is ineffective in this situation as the excluded stomach is inaccessible via this route.

As is the case with a suspected anastomotic leak, diagnostic imaging with either CT or UGI contrast study may prove useful in confirming the diagnosis of a post-operative SBO. However, the sensitivity of these modalities is poor, and the decision to proceed to surgical intervention is predominantly clinical. Abdominal pain and hemodynamic instability warrants prompt surgical intervention, even in the absence of nausea, vomiting, and obstipation. Ischemic and frankly gangrenous bowel is not infrequently discovered upon re-exploration in this patient population.

17.3.5 Rhabdomyolysis

Pressure-induced rhabdomyolysis (RML) is a rare but well-described post-operative complication that results from prolonged, unrelieved pressure to muscle during surgery (see Chapter 18). Major risk factors include prolonged operative time and obesity. Rhabdomyolysis following bariatric surgery may affect the lower extremity, gluteal, or lumbar regions. In a recent review, mean operating room time, mean BMI (67 kg m^{-2} vs. 55 kg m^{-2}) male gender and the incidence of diabetes mellitus were significantly greater in patients who developed RML [54]. Prevention of RML and related complications includes attention to padding and positioning on the operating table, minimization of operative time, and maintenance of a high index of suspicion post-operatively.

The most common clinical presentation of RML is muscular pain and numbness. Muscle breakdown leads to the release of intracellular myoglobin and creatine phosphokinase (CPK). Myoglobinuria is suspected in the presence of brown urine, and confirmed by a positive urine dipstick test for hemoglobin in the absence of erythrocytes on urinalysis. Serum CPK concentrations peak on the first to fifth post-operative day, and usually resolve within two weeks of surgery.

Patients suspected of having RML should be monitored in the ICU. Treatment is instituted once the CPK concentration increases above 5000 IU l^{-1}, including aggressive hydration and diuresis with mannitol to a target urine output of 1.5 ml kg^{-1} h^{-1}. Mannitol mobilizes muscular interstitial fluid and increases renal tubular flow. Alkalization of urine with sodium bicarbonate increases the solubility of myoglobin in a pH-dependent manner.

Compartment syndrome, acute renal failure, and mortality may complicate RML. Acute renal failure results from hypovolemia, tubular obstruction, acidosis, and free radical release. Factors predictive of renal failure in RML include age > 70 years, serum CPK concentration > 16 000 IU l^{-1}, degree of hypoalbuminemia, and sepsis. Fortunately, complete recovery of tubular function is the norm, albeit after a variable period of renal replacement therapy. Hemofiltration has the added advantage of rapid clearance of myoglobin.

17.4 Conclusions

The obese critically ill patient has traditionally been considered at increased risk of mortality due to both underlying organ dysfunction and increased difficulty

Table 17.3 Risk factors for intensive care unit admission, and post-operative complications following bariatric surgery

Male gender
Age > 50 years
BMI > 60 kg m^{-2}
Diabetes mellitus
Cardiovascular disease
Obstructive sleep apnea syndrome
Venous stasis
Intra-operative complications

encountered during routine ICU procedures (e.g., endotracheal intubation, venous catheter placement). Conversely, in what has been termed the "obesity paradox," an increase in both adipose and muscle reserve, alterations in cell-mediated immunity, and increased lipoprotein concentrations may confer a survival advantage upon the obese, critically ill patient [55].

Outcomes research, conducted at both the single-institution and national level, has failed to reach a consensus regarding an association between obesity and mortality of critical illness, and this issue remains fervently contested within the critical care literature. Reported associations range from a protective effect of obesity to a markedly increased risk-adjusted likelihood of mortality. However, the few studies that have investigated specifically MO, critically ill surgical patients [1, 56] have found that this patient group is at increased risk of both morbidity and mortality of critical illness. Future studies employing rigorous methodology are warranted.

Far less information is available specifically as to the course of bariatric surgical patients requiring ICU care. In a retrospective review of patients undergoing either vertical banded gastroplasty or gastric bypass, Helling *et al*. noted that hospital length of stay doubled for those patients requiring greater than 24 hours of ICU care following surgery [18]. Factors predictive of ICU admission after bariatric surgery are summarized in Table 17.3.

Bariatric surgery and associated weight loss have been shown to improve cardiovascular risk factors, cardiac structure and function, and the clinical course of pre-existing cardiovascular disease. This clinical improvement is also striking for disorders of the respiratory system and in the resolution of diabetes as well. Nonetheless the MO patient, particularly the patient with the metabolic syndrome is a virtual physiologic "tinderbox" that requires proactive management to rapidly intervene in cases of clinical deterioration. Developing good reasoning skills, based on the understanding of the altered physiology of these patients, is essential to problem solving in the critical care setting.

References

1. Nasraway SA, Jr., Albert M, Donnelly AM, *et al*. Morbid obesity is an independent determinant of death among surgical critically ill patients. *Crit Care Med* 2006; **34**: 964–70.
2. Nguyen NT, Goldman C, Rosenquist CJ, *et al*. Laparoscopic versus open gastric bypass: a randomized study of outcomes, quality of life, and costs. *Ann Surg* 2001; **234**: 279–89.
3. van den Broek RJ, Buise MP, van Dielen FM, Bindels AJ, van Zundert AA, Smulders JF. Characteristics and outcome of patients admitted to the ICU following bariatric surgery. *Obes Surg* 2009; **19**: 560–64.
4. Yeats M, Wedergren S, Fox N, Thompson JS. The use and modification of clinical pathways to achieve specific outcomes in bariatric surgery. *Am Surg* 2005; **71**: 152–4.
5. Cendan JC, Abu-aouf D, Gabrielli A, *et al*. Utilization of intensive care resources in bariatric surgery. *Obes Surg* 2005; **15**: 1247–51.
6. Nguyen NT, Wolfe BM. The physiologic effects of pneumoperitoneum in the morbidly obese. *Ann Surg* 2005; **241**: 219–26.
7. Nguyen NT, Ho HS, Fleming NW, *et al*. Cardiac function during laparoscopic vs. open gastric bypass: a randomized comparison. *Surg Endosc* 2002; **16**: 78–83.
8. Lopez-Jimenez F, Bhatia S, Collazo-Clavell ML, *et al*. Safety and efficacy of bariatric surgery in patients with coronary artery disease. *Mayo Clin Proc* 2005; **80**: 1157–62.
9. Alsabrook GD, Goodman HR, Alexander JW. Gastric bypass for morbidly obese patients with established cardiac disease. *Obes Surg* 2006; **16**: 1272–7.
10. Livingston EH, Huerta S, Arthur D, *et al*. Male gender is a predictor for morbidity and age a predictor of mortality for patients undergoing bypass surgery. *Ann Surg* 2002; **236**: 576–82.
11. Vaughan RW, Bauer S, Wise L. Volume and pH of gastric juice in obese patients. *Anesthesiology* 1975; **43**: 686–9.
12. Zacchi P, Mearin F, Humbert P, *et al*. Effect of obesity on gastroesophageal resistance to flow in man. *Dig Dis Sci* 1991; **36**: 1473–80.
13. Vila P, Valles CJ, Canet J, *et al*. Acid aspiration in morbidly obese patients: Famotidine vs. ranitidine. *Anaesthesia* 1991; **46**: 967–9.
14. Pelosi P, Ravagnan I, Giurati G, *et al*. Positive end-expiratory pressure improves respiratory function in

obese but not in normal subjects during anesthesia and paralysis. *Anesthesiology* 1999; **91**: 1221–31.

15. Burns SM, Egloff MB, Ryan B, *et al*. Effect of body position on spontaneous respiratory rate and tidal volume in patients with obesity, abdominal distension and ascites. *Am J Crit Care* 1994; **3**: 102–6.
16. Valenza F, Vaginelli F., Tiby A., *et al*. Effects of beach chair position, positive end-expiratory pressure and pneumoperitoneum on respiratory function in morbidly obese patients during anesthesia and paralysis. *Anesthesiology* 2007; **107**: 725–32.
17. Hogue CW Jr. Stearns JD, Colantuoni E, *et al*. The impact of obesity on outcomes after critical illness: a meta-analysis. *Intensive Care Med* 2009; **35**: 1152–70.
18. Helling TS, Willoughby TL, Maxfield DM, Ryan P. Determinants of the need for intensive care and prolonged mechanical ventilation in patients undergoing baratric surgery. *Obes Surg* 2004; **14**: 1036–41.
19. Poulose BK, Griffen MR, Zhu Y, *et al*. National analysis of adverse patient safety events in bariatric surgery. *Am Surg* 2005; **71**: 406–13.
20. The Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med;* 2000; **342**: 1301–8.
21. El-Solh A, Sikka P, Bozkanat E, *et al*. Morbid obesity in the medical ICU. *Chest* 2001; **120**: 1989–97.
22. Rose DK, Cohen MM, Wigglesworth DF, DeBoer DP. Critical respiratory events in the postanesthesia care unit. *Anesthesiology* 1994; **81**: 410–18.
23. Mansharamani NG, Koziel H, Garland R, *et al*. Safety of bedside percutaneous dilatational tracheostomy in obese patients in the ICU. *Chest* 2000; **117**: 1426–9.
24. Byhahn C, Lischke V, Meninger D, *et al*. Peri-operative complications during percutaneous tracheostomy in obese patients. *Anaesthesia* 2005; **60**: 12–15.
25. Heyrosa MG, Melniczek DM, Rovito P, Nicholas GG. Percutaneous tracheostomy: a safe procedure in the morbidly obese. *J Am Coll Surg*. 2006; **202**: 618–22.
26. Jeevanandam M, Young DH, Schiller WR. Obesity and the metabolic response to severe trauma in man. *J Clin Invest* 1991; **87**: 262–9.
27. Dickerson RN, Boschert KJ, Kudsk KA, Brown RO. Hypocaloric enteral tube feeding in critically ill obese patients. *Nutrition* 2002; **18**: 241–6.
28. Van den Berghe G, Wouters P, Weekers F, *et al*. Intensive insulin therapy in the critically ill patients. *N Engl J Med* 2001; **345**: 1359–67.
29. Van den Berghe G, Wilmer A, Hermans G, *et al*. Intensive insulin therapy in medical intensive care patients. *N Engl J Med* 2006; **354**: 449–61.
30. Pieracci FM, Hydo LJ, Eachempati SR, *et al*. Higher body mass index predicts need for insulin but neither hyperglycemia, nosocomial infection, nor mortality of critically ill surgical patients. *Surg Infect (Larchmt)* 2008; **9:** 121–30.
31. Purnell JQ, Brandon DD, Isabelle LM, Loriaux DL, Samuels, MH. Association of 24-hour cortisol production rates, cortisol-binding globulin, and plasma-free cortisol levels with body composition, leptin levels, and aging in adult men and women. *J Clin Endocrinol Metab* 2004; **89**: 281–7.
32. Marik PE, Pastores SM, Annane D, *et al*. American College of Critical Care Medicine. Recommendations for the diagnosis and management of corticosteroid insufficiency in critically ill adult patients: consensus statements from an international task force by the American College of Critical Care Medicine. *Crit Care Med* 2008; **36**: 1937–49.
33. Snider RD, Kruse JA, Bander JJ, Dunn GH. Accuracy of estimated creatinine clearance in obese patients with stable renal function in the intensive care unit. *Pharmacother* 1995; **15**: 747–53.
34. Cheymol G. Clinical pharmacokinetics of drugs in obesity: An update. *Clin Pharmacokinet* 1993; **25**: 103–14.
35. Greenblatt DJ, Abernethy DR, Locniskar A, *et al*. Effect of age, gender, and obesity on midazolam kinetics. *Anesthesia* 1984; **61**: 27–35.
36. Kress JP, Pohlman AS, O'Connor MF, Hall JB. Daily interruption of sedative infusions in critically ill patients undergoing mechanical ventilation. *N Engl J Med* 2000; **342**: 1471–7.
37. Blouin RA, Bauer LA, Miller DD, *et al*. Vancomycin pharmacokinetics in normal and morbidly obese subjects. *Antimicrob Agents Chemother* 1982; **21**: 575–80.
38. Beardon DT, Rodvold KA. Dosing adjustment for antibacterials in obese patients: Applying clinical pharmacokinetics. *Clin Pharmacokinet* 2000; **38**: 415–26.
39. Stein GE, Schooley SL, Peloquin CA, *et al*. Pharmacokinetics and pharmacodynamics of linezolid in obese patient with cellulitis. *Ann Pharmacother* 2005; **39**: 427–32.
40. Traynor AM, Nafziger AN, Bertino JS. Aminoglycoside dosing weight correction factors for patients of various body sizes. *Antimicrob Agents Chemother* 1995; **39**: 545–8.
41. Allard S, Kinzig M, Bovin G, *et al*. Intravenous ciprofloxacin disposition in obesity. *Clin Pharmacol Ther* 1993; **54**: 368–73.
42. Bernard GR, Vincent J, Laterre P, *et al*. Efficacy and safety of recombinant human activated protein C for severe sepsis. *New Engl J Med* 2001; **344**: 699–709.

43. Levy H, Small D, Heiselman DE, *et al*. Obesity does not alter the pharmacokinetics of drotrecogin alpa (activated) in severe sepsis. *Ann Pharmacother* 2005; **39**: 262–7.
44. Mason EE, Renuist KE, Huang YH, *et al*. Causes of 30-day bariatric surgery mortality: with an emphasis on bypass obstruction. *Obes Surg* 2007; **17**: 9–14.
45. Hamilton EC, Sims TL, Hamilton TT, *et al*. Clinical predictors of leak after laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Surg Endosc* 2003; **17**: 679–84.
46. Lee S, Carmody B, Wolfe L, *et al*. Effect of location and speed of diagnosis on anastomotic leak outcomes in 3828 bypass cases. *J Gastrointest Surg* 2007; **1**: 708–13.
47. Wilson JA, Romagnuolo J, Byrne TK, Morgan K, Wilson FA. Predictors of endoscopic findings after Roux-en-Y gastric bypass. *Am J Gastroenterol* 2006; **101**: 2194–9.
48. Gonzalez R, Haines K, Nelson LG, *et al*. Predictive factors of thromboembolic events in patients undergoing Roux-en-Y gastric bypass. *Surg Obes Relat Dis* 2006; **2**: 30–5.
49. Podnos YD, Jimenez JC, Wilson SE, *et al*. Complications after laparoscopic gastric bypass. *Arch Surg* 2003; **138**: 957–61.
50. Scholton DJ, Hoedema RM, Scholten SE. A comparison of two different prophylactic dose regimens of low molecular weight heparin in bariatric surgery. *Obes Surg* 2002; **12**: 19–24.
51. Gerts WH, Heit JA, Clagett GP, *et al*. Prevention of venous thromboembolism. *Chest* 2001; **119**: 132S-75S.
52. Hamad GG, Choban PS. Enoxaparin for thromboprophylaxis in morbidly obese patients undergoing bariatric surgery: findings of the prophylaxis against VTE outcomes in bariatric surgery patients receiving enoxaparin (PROBE) study. *Obes Surg* 2005; **15**: 1368–74.
53. Sapala JA, Wood MH, Schuhknecht MP, Sapala MA. Fatal pulmonary embolism after bariatric operations for morbid obesity: a 24-year retrospective analysis. *Obes Surg* 2003; **13**: 819–25.
54. Bostanjian D, Anthone GJ, Hamoui N, Crookes PF. Rhabdomyolysis of gluteal muscles leading to renal failure: A potentially fatal complication of surgery in the morbidly obese. *Obes Surg* 2003; **13**: 302–5.
55. Marik PE. The paradoxical effect of obesity on outcomes in critically ill patients. *Crit Care Med* 2006; **34**: 1251–3.
56. Bercault N, Boulain T, Kuteifan K, Wolf M, Runge I, Fleury JC. Obesity-related excess mortality rate in an adult intensive care unit: A risk-adjusted matched cohort study. *Crit Care Med* 2004; **32**: 998–1003.

Chapter 18

Post-operative rhabdomyolysis

João Ettinger, Paulo Batista and Euler Ázaro

18.1 Introduction

The increasing number of surgical patients with extreme obesity has increased the incidence of a post-operative complication that occurs more frequently in obese patients, rhabdomyolysis (RML). The incidence of post-operative RML in bariatric surgical patients has been reported as from 6 to 75% [1–3] (Table 18.1). Rhabdomyolysis occurs due to prolonged muscle compression in any non-physiologic surgical position, most often in procedures lasting longer than 4 [4] to 5 [3, 5] hours. In MO patients, excessive weight, the presence of diabetes, American Society of Anesthesiologists physical status >II [4], and prolonged surgical duration are associated with RML [5]. Potentially full recovery can be expected with early diagnosis and treatment [6]. Rhabdomyolysis is a clinical and biochemical syndrome caused by skeletal muscle necrosis, which results in extravasation of toxic intracellular contents from the myocytes into the circulatory system [7–12]. If prevention of RML is not achieved, or the diagnosis is delayed, and if appropriate treatment is not instituted, serious complications and even death can occur.

18.2 Pathophysiology

Rhabdomyolysis results from the breakdown of striated muscle of any part of the human body [5–7, 13]. Muscle injury leads to disruption of the internal cellular structures, and the damaged membranes allow the uncontrolled influx of sodium, chloride, calcium, and water down their electrochemical gradients. Large amounts of intravascular fluid (up to 12 l) can leave the circulation and become sequestered in damaged muscle tissue. This fluid shift produces an intravascular hypovolemia and, subsequently, hemodynamic instability [14,15]. The dramatic decrease in plasma volume leads to vasoconstriction, pre-renal failure and, eventually, acute intrarenal failure [13]. Chloride and calcium ions also enter the cells, causing serum hypocalcemia and calcium deposition in skeletal muscle and renal tissues [16].

Potassium is the most import intracellular component that leaks out of the damaged skeletal muscle. Because this electrolyte is moving from an intracellular area of high concentration into the serum, where a low concentration is normal, hyperkalemia leading to cardiotoxic effects and dysrhythmias can result [17]. Phosphate also leaves the cells, producing hyperphosphatemia. Injured myocytes also leak lactic acid and other organic acids, promoting metabolic acidosis and aciduria. Purines released from disintegrating cells are metabolized to uric acid producing hyperuricemia [5, 18].

Myoglobin is an oxygen-carrying molecule that gives muscle its red-brown color. Lysis of as little as 100 g of skeletal muscle results in myoglobinuria. Myoglobin is nephrotoxic in patients with concomitant oliguria and aciduria [5, 19].

Thromboplastin and tissue plasminogen are released from injured muscle tissue, making patients with RML susceptible to disseminated intravascular coagulation (DIC), mainly when associated with sepsis [15, 18–22].

Marked increases in serum levels of creatinine phosphokinase (CPK) occur in RML. Creatinine phosphokinase has no toxic effects, and elevated plasma CPK levels are simply a marker of increased permeability of muscle membranes. However, high values are pathognomonic for RML, because no other condition will lead to such extreme CPK elevations [23].

18.3 Rhabdomyolysis and morbid obesity

Rhabdomyolysis in MO patients is caused by tissue compression after extended periods of immobilization. This pressure damage leads to muscle ischemia,

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

Table 18.1 Published research articles about rhabdomyolysis and bariatric surgery

Source	N	Study type	Technique	Total RML	Mild RML CPK < 4000 UI/l^{-1}	Severe RML CPK > 4000 UI/l^{-1}	Operative time–Mean – min	Mean BMI
Khurana *et al.* (2004)	353	Retrospective	Laparoscopic DS		Not studied	1.4% (5 patients)	246	56 kg m^{-2} (patients with RML)
Mognol *et al.* (2004)	66	Prospective	LAGB LRYGB	22.7% (15 patients)	15.2% (10 patients)	7.5% (5 patients)	110 LAGB 390 LRYGB	43.9 kg m^{-2} 58.8 kg m^{-2}
Carvalho *et al.* (2006) *Obes Surg*	98	Prospective	ORYGB	37.8% (38 patients)	37.8% (38 patients)	None	220	43.2 kg m^{-2}
Faintuch *et al.* (2006) *Obes Surg*	129	Retrospective	ORYGB	12.9% (16 patients)	8.5% (11 patients)	3.8% (5 patients)	320 mild RML 340 severe RML	50.8 kg m^{-2} (mild RML) 54.6 kg m^{-2} (severe RML)
Lagandré *et al.* (2006) *Obes Surg*	49	Prospective	LAGB Intestinal bypass RYGB	26.5% (13 patients)	24.5% (12 patients)	2.04% (1 patient)	195 without RML 272 with RML	49.7 kg m^{-2}
	114	Retrospective	ORYGB LRYGB	7% (8 patients)	7% (8 patients)	None	182 ORYGB 171 LRYGB 176 total	44.6 kg m^{-2} ORYGB 41.5 kg m^{-2} LRYGB 43.1 kg m^{-2} kg m^{-2} Total

From: Ref [1].
ORYGB, open Roux-en-Y gastric bypass; LRYGB, laparoscopic Roux-en-Y gastric bypass; LAGB, laparoscopic adjustable gastric banding; DS, duodenal switch; RML, rhabdomyolysis.

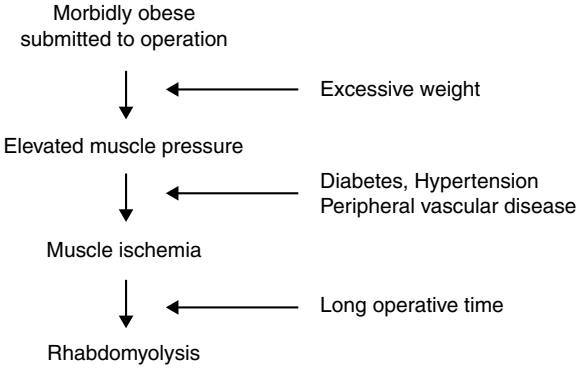

Figure 18.1 Rhabdomyolysis in MO surgical patients is caused by tissue compression after extended periods of immobilization. Pressure damage leads to muscle ischemia which interferes with oxygen delivery to the cells. Besides long duration surgery with prolonged tissue ischemia, additional risk factors include the presence of diabetes, hypertension and peripheral vascular disease.

which interferes with oxygen delivery to the cells, thereby limiting production of adenosine triphosphate (ATP) and the function of sodium-potassium ATPase membrane pumps. Rhabdomyolysis with serious complications (hyperkalemia, hypocalcemia, hyperphosphatemia, compartment syndrome, DIC, cardiac disorders, acute kidney injury, and death) can result (Figure 18.1).

Animal studies have demonstrated myonecrosis when an intra-compartmental pressure of 30 mmHg is applied for 4–8 hours [5]. The recognized risk factors for the development of post-operative RML are prolonged duration of operation, massive obesity, surgical compressive positioning, and endocrine or metabolic disorders such as diabetes and hypertension. Another related factor, peripheral vascular disease, is associated with compartmental syndrome [24].

Long duration of surgery promotes tissue compression and further ischemia. Although RML is more common in obese surgical patients, RML has occurred after prolonged operations in non-obese patients. Morbidly obese patients are at risk of developing RML during shorter operative procedures (< 7 hours). Obesity (> 30% above ideal weight) is associated with increased tissue compression [6]. Rhabdomyolysis is also a complication of non-physiologic positions, and has occurred with patients in the seated, lateral decubitus, prone, exaggerated or high lithotomy, genupectoral, knee-chest or tucked, supine and hyperlordotic positions [25–27]. Super-obese male patients (BMI >50 kg m^{-2}) with hypertension, diabetes, and peripheral vascular disease are at greatest risk for RML. These factors are not independent: super-obese male patients

Table 18.2 Methods to prevent rhabdomyolysis in MO patients during surgery

Padding pressure areas
Use of pneumatic beds during operation
Use of two combined surgical tables
Optimal position on surgical table
Limit surgical time :
• Reduce weight before bariatric surgery or perform surgery in two stages
• Avoid early in the learning curve operating on super-obese patients
Changing patient position intra- and post-operatively
Aggressive fluid replacement peri-operatively
Early ambulation
Discontinue statin therapy
Correct risk factors for RML after surgery

From: Ref [57].

are more likely to be diabetic and hypertensive, and bariatric surgery in this population may be more difficult and likely to be associated with longer surgery duration and, consequently, more tissue compression. Other potential etiologic factors include family history of muscle disease and the consumption of certain drugs, notably statins [28].

18.4 Prevention of rhabdomyolysis

Prevention of RML avoids the serious outcomes of this complication (Table 18.2). Bostanjain *et al.* [3] concluded that prevention starts with careful padding on the operative table. Mognol *et al.* [2] likewise stated that in MO patients, RML prevention includes adequate padding at all pressure-points during surgery. Khurana *et al.* [29] advise protective padding added around the hips, shoulders and buttocks (areas adjacent to bone prominences) to minimize surface and deeper pressure by distributing pressure over a greater surface area [29].

Iseri *et al.* [25] suggest the use of pneumatic beds during surgery to prevent the occurrence of RML (Figure 18.2). Hofmann and Stoller [26] recommend that obese surgical patients position themselves on the surgical table before induction of anesthesia, to the most appropriate position, to avoid positions that can increase muscle compression. These authors also suggest the use of two combined surgical tables to decrease the pressure on the back surface of the massively obese patient. Wiltshire *et al.* [27] recommend that special attention be given to protect injured and

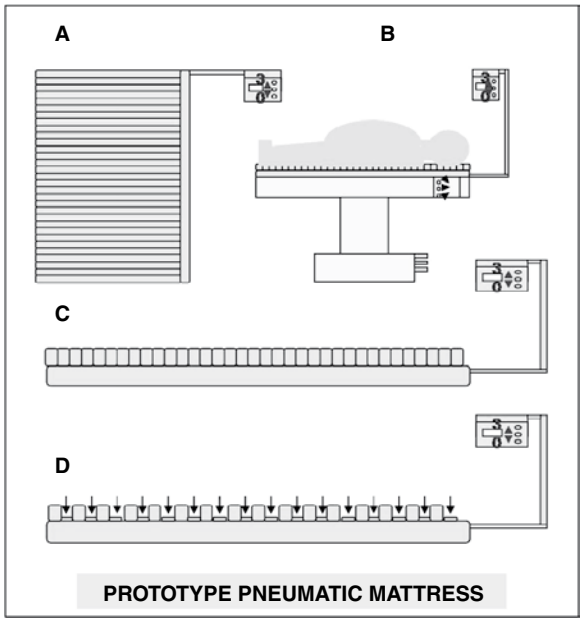

Figure 18.2 The use of pneumatic beds during surgery, similar to the type shown in this figure, might prevent the occurrence of rhabdomyolysis.

uninjured muscle tissue in the MO patient. This can be achieved by frequently changing patient position, both intra-operatively (for operations lasting > 2–3 hours) and post-operatively. Bocca *et al*. also assert that preventive measures such as good positioning and perioperative repositioning of the patient can prevent RML [30]. Bostanjian *et al.* [3] emphasize that the duration of immobilization is greater for very heavy patients. This is not only because the operation takes longer but also because other aspects of the operation including the placement of central lines or arterial lines are more likely to be difficult and time-consuming. The longer the immobilization, the greater is the RML risk, so one potential new solution proposed by Regan *et al.* [31] and others [32] is to decrease the longer operative time by dividing the procedure into two stages, doing a gastric sleeve resection initially, and then when the patient has lost considerable weight performing the definitive bypass. Regan's group [31] concluded that laparoscopic sleeve gastrectomy with second-stage Roux-en-Y gastric bypass is feasible and effective. This two-stage approach is a reasonable alternative for surgical treatment of the high-risk super-super-obese (BMI > 60 kg m^{-2}) patient. Mognol *et al.* [2] state that the gastric bypass in two stages is ideal for the MO hypertensive male with type 2 diabetes. Another way to limit the duration of surgery in high-risk patients

Table 18.3 Intra-operative prevention of rhabdomyolysis

Measures
Hydration > 13 ml kg^{-1} h^{-1}
Maintain diuresis > 2.3 ml $kg^{-1}h^{-1}$
Operative time < 2 h

From: Ref [56].

is for surgeons early in their learning curve not to select patients who fall into this group, or to offer such patients a staged procedure [3]. It is also important to have a hospital bed designed for MO patients to be used post-operatively. Aggressive intra-operative and post-operative fluid replacement is another means of preventing RML [2,13] (Table 18.3). Iseri *et al.* [25] recommend that high urine output be maintained with IV fluids and diuretics, before, during and after surgery.

18.5 Diagnosis of rhabdomyolysis

18.5.1 Clinical findings and physical evaluation

The initial clinical expression of RML can be sudden, and an early diagnosis requires a high degree of suspicion [5]. The syndrome has local and systemic features. Local signs and symptoms are non-specific and may include muscle pain, tenderness, swelling, bruising, and weakness. Systemic features include tea-colored urine, fever, malaise, nausea, emesis, confusion, agitation, delirium, and anuria [6] (Table 18.4). During the physical examination, decubitus ulcer and eruptions can be present in pressure zones, mainly at the hips, limbs, and buttocks [13, 27] (Figure 18.3). Usually, the first systemic clinical sign is the appearance of urine with altered color that can range from pink, to brown and black [5, 6, 12]. Myoglobinuria is suspected with the presence of altered urine color [12] and requires differential diagnosis among several entities [27].

18.5.2 Laboratory findings

Although history and physical examination can provide clues, the actual diagnosis of RML is confirmed by laboratory studies [5, 10, 29]. Once RML is suspected, the diagnosis can be established by high serum levels of CPK. A serum CPK five times the normal value is considered as a biochemical diagnosis of RML [2]. The elevation in CPK levels is the most sensitive diagnostic evidence of muscle injury [3, 6] and is present in 100% of RML cases [5]. When the RML syndrome is present,

Table 18.4 Clinical features of rhabdomyolysis

Local features	Systemic features
Muscle pain	Tea-colored urine
Tenderness	Fever
Swelling	Nausea
Bruising	Malaise
Weakness	Emesis
	Confusion
	Agitation
	Delirium
	Anuria

From: Ref [6].

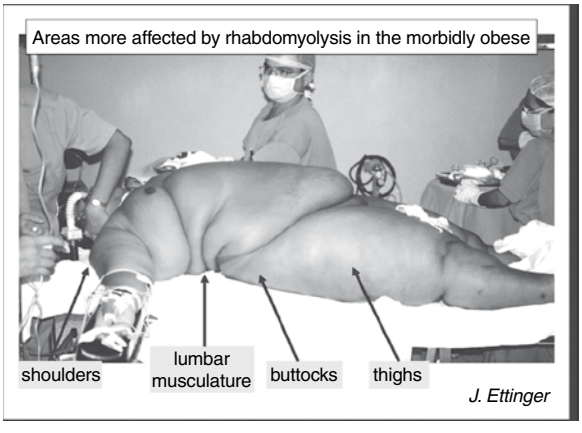

Figure 18.3 Muscle groups most susceptible to pressure injury in the MO surgical patient.

large quantities of CPK are released into the blood system and peak concentrations of 100 000 IU ml^{-1} or more are not unusual. No other condition will cause such extreme CPK elevations [5]. Serum CPK peak values occur 4–7 days after injury and remain elevated for up to 12 days [27]. In some cases, the CPK isoenzymes MM and MB are measured to distinguish a cardiac from a skeletal source [12]. An ECG must also be done to differentiate RML from myocardial infarction [2].

Urinary myoglobin provokes a typical reddish-brown color. Myoglobin can be detected in urine when values exceed 1500–3000 ng ml^{-1} [33]. Kim *et al.* [34] found in a prospective study that a urine myoglobin concentration >300 ng ml^{-1} was associated with an increased risk of RML and acute renal failure (ARF). Urinalysis in patients with RML will also reveal the presence of protein, brown casts in tubules and uric acid crystals and may reflect electrolyte wasting consistent with renal failure [5].

In a retrospective analysis, Grover *et al.* [35] studied the lack of clinical utility of urine myoglobin detection by microconcentrator ultrafiltration in the diagnosis of RML. They concluded that this method has a poor and clinically inadequate sensitivity in detection and diagnosis of RML. When RML is present, there is generally an increase in blood urea nitrogen and creatinine due to prerenal causes of ARF from dehydration and myoglobinuria [36] Both ARF and increased release of creatine from skeletal muscle cause the serum concentration of urea nitrogen and creatinine to increase in RML.

A classical pattern of changes in serum electrolytes occurs in RML. At the outset, serum levels of potassium and phosphate increase as these components are released from the cells, and then levels decrease as they are excreted in the urine. Serum concentration of calcium initially decreases as calcium moves into the damaged muscle cells, then gradually increases during the recovery phase due to the release of calcium from injured muscle and elevated 1,25-dihydroxyvitamin D levels [33]. Severe hyperuricemia may develop because of the release of purines from damaged muscle cells [33, 36]. High anion acidosis can also occur with RML [36] Clotting studies are useful for detecting DIC [5]. Serum aspartate aminotransferase (AST), alanine aminotranferease (ALT), aldolase, troponin I and lactate dehydrogenase enzymes can all increase due to muscular injury [27, 36]. Serum carbonic anhydrase III has also been suggested as a marker for the diagnosis of RML [27].

Blood gas analysis is helpful for detecting underlying respiratory and metabolic acidosis and monitoring sodium bicarbonate therapy [5]. Muckart *et al.* [37] concluded in a prospective study that venous bicarbonate (VBC) concentration has an important role as a predictive factor that allows identification of patients at risk of developing myoglobin-induced acute kidney injury. A VBC < 17 mmol l^{-1} was significantly predictive of ARF development [37].

In a retrospective study, Al-Shekhlee *et al.* [38] investigated the electromyographic (EMG) features of acute RML. They concluded that EMG is an important diagnostic tool in the work-up of patients presenting with acute or sub-acute severe muscle weakness and significantly elevated CPK, when the differential diagnosis includes RML and inflammatory myopathies.

Table 18.5 summarizes the early and late complications of RML, and Table 18.6 summarizes the risk factors for the development of acute renal failure.

Table 18.5 Complications of rhabdomyolysis

Early	Late
Hypercalcemia	Acute renal failure
Hypocalcemia	Disseminated intravascular coagulation
Hepatic inflammation	Compartment syndrome
Cardiac arrhythmia	
Compartment syndrome	

From: Ref [6] .

Table 18.6 Risk factors for acute renal failure from rhabdomyolysis following bariatric surgery

Hypoalbuminemia
Hyperkalemia or hypophosphatemia
Sepsis
CPK peak > 6 000 IU l^{-1}
Hypertension
Diabetes
Pre-existing azotemia

From: Ref [2].

18.5.3 Image examinations

Radiographic evaluation can also be valuable for diagnosing RML when clinical findings and physical examination are not conclusive (Table 18.7). Both MRI and CT are helpful in the diagnosis of RML [39]; MRI accurately identifies muscular edema in the affected muscle groups. In Lamminen *et al.*'s [40] prospective study, MRI had a higher sensitivity in the detection of abnormal muscles than CT or ultrasonography (100%, 62% and 42%, respectively). Evaluation by CT can reveal muscle necrosis and calcification that occur early in the course of RML [41]. For the diagnosis of RML, CT must be non-contrast enhanced to avoid acute renal failure [42]. ^{111}Indium-labeled antimyosin monoclonal antibody and technetium-^{99}m pyrophosphate (^{99}mTc-PYP) scintigraphy have also been used to make the diagnosis of RML to evaluate muscle injury [27]. Ultrasonography has also been known to have some value in identifying injured musculature in RML by revealing hyperechoic areas within the muscles examined [43]. Plain muscle X-ray does not have value in RML [44]. A muscle biopsy in the affected site can be done if any doubt remains [27].

Table 18.7 Image examinations to detect rhabdomyolysis

Study	Finding
Magnetic resonance imaging	Muscular edema
Computed tomography	Muscle necrosis and calcification
Ultrasound	Hyperechoic areas
Technetium-99m scintigraphy	Accumulation of the radioactivity in the damaged skeletal muscle

From: Ref [58].

18.6 Treatment

The treatment of RML is geared toward preserving renal function, by preventing factors that can lead to ARF [45]. Early recognition allows the administration of intravenous fluids, bicarbonate, and mannitol [3, 5, 10, 46]. These measures help to prevent volume depletion, tubular obstruction, aciduria, and free radical release, which is the mechanism for renal failure in RML [3, 10]. Hypovolemia may result from sequestration of water into muscles and must be prevented by the early and aggressive administration of intravenous fluids [6, 47]. Expanding the intravascular volume maximizes renal excretion by flushing out the tubular debris and limiting the time nephrotoxins are in contact with renal tissues [5, 47]. Treatment of RML requires aggressive administration of intravenous fluids to ensure urine output >1.5 ml $kg^{-1}h^{-1}$ [48] or 150–300 ml $^{-1}h^{-1}$ until myoglobinuria has ceased [5, 6, 10, 14]. Maintaining a urine output this high may require intravenous infusion of between 500 and 1000 ml h^{-1} [14]. All patients should have a urinary catheter placed in order to adequately monitor fluid output [49]. Sinert *et al.* [50] showed in a retrospective chart analysis that forced diuresis within the first 6 hours of admission prevented episodes of ARF. Diuretics are also used, mainly mannitol and loop diuretics. The addition of mannitol to the fluid regimen serves several purposes. Mannitol is an osmotic agent that attracts fluids from the interstitial compartment thus counterbalancing hypovolemia and reducing muscular swelling and nerve compression. Mannitol is an osmotic diuretic that increases urinary flow and may prevent obstructive myoglobin casts, and mannitol scavenges free radicals. Many authors assert that loop diuretics (furosemide, bumetanide, and torsemide) must be used if fluids and mannitol are insufficient to maintain a brisk urine output [10, 14]. They

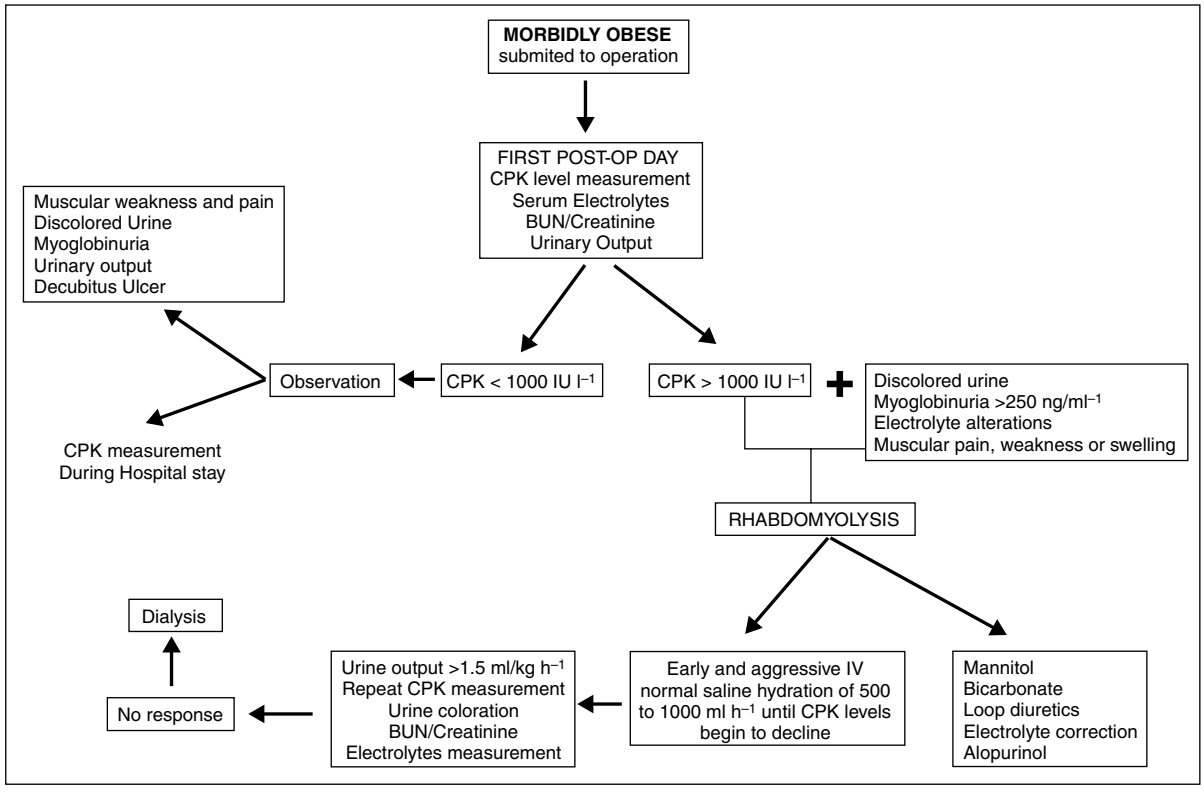

Figure 18.4 An algorithm for the treatment of rhabdomyolysis. Electrolyte disorders should be prevented or promptly treated CPK, creatine phosphokinase, BUN.

increase tubular flow and calcium losses and decrease the risk of precipitation of myoglobin [51], although they may acidify the urine [51, 52]. However, there is no evidence that diuretics improve the final outcome [6]. These aggressive and successful measures were first described in trauma patients who had traumatic RML [53], but to date no randomized controlled trial has shown unquestionable results in preventing acute kidney injury with the use of diuretics. Dialysis does not reduce myoglobin [54].

The use of sodium bicarbonate helps to correct the acidosis induced by the release of protons from damaged muscles to prevent precipitation of myoglobin in the tubules and reduce the risk of hyperkalemia [51]. Bicarbonate and acetazolamide are used for producing more alkaline urine when blood pH is > 7.45 [48]. Some investigators assert that the urine must be alkalinized to pH 6.0 [18], 6.5 [55], 7.0 [10], or even 7.53 [4] to prevent the dissociation of myoglobin into its nephrotoxic components. On the other hand, there are also some concerns about the use of sodium bicarbonate because it may worsen hypocalcemia or precipitate calcium phosphate deposition in various tissues [6]. Allopurinol may be useful because it reduces the production of uric acid and also acts as a free-radical scavenger. Another purine analog pentoxyfilline has been considered in the management of RML because of its capacity to enhance capillary flow and decrease neutrophil adhesion and cytokine release [51].

Electrolyte disorders should be prevented or promptly treated [33]. Control of hyperkalemia is an important therapeutic goal. Calcium salts and calcium kayexalate (sodium polystyrene sulfanate and exchange resin) should be used with caution because they enhance the risk of intramuscular calcium deposition [51]. Hypocalcemia usually does not require correction, particularly because this would increase the risk of intramuscular calcium deposition [51]. Dialysis is necessary if the kidneys no longer respond to the above-mentioned supportive measures and severe renal dysfunction has set in [2, 48]. Dialysis is indicated not only in patients with overt hyperkalemia, but also in patients whose serum potassium rises rapidly and those with acidosis [51] (Figure 18.4).

Compartment syndrome may be an early or late complication that results mainly from direct muscle injury [5, 6, 33]. This complication occurs primarily in muscles whose expansion is limited by tight fascia. Peripheral pulses may still be palpable, and in these cases, nerve deficits (mainly sensory) are the more important finding. Compartment syndrome may develop or worsen during fluid resuscitation due to the development of edema of limbs and/or muscles. Decompressive fasciotomy, muscular debridement, and escharotomies should also be considered in patients with evidence of neurovascular compression and decubitus ulcer if the compartment pressure is >30 mmHg [5, 6, 30, 33]. Rhabdomyolysis is a potentially fatal disease that needs maximum attention by the surgeon who operates on morbidly obese subjects. Adequate care to prevent this syndrome is necessary and prompt treatment must be instituted when diagnosed.

References

1. Ettinger JEMT, Marcílio de Souza CA, Ázaro E *et al.* Clinical features of rhabdomyolysis after open and laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2008; **18**: 635–43.
2. Mognol P, Vignes S, Chosidow D, *et al.* Rhabdomyolysis after laparoscopic bariatric surgery. *Obes Surg* 2004; **14**: 91–4.
3. Bostanjian D, Anthone GJ, Hamoui N, *et al.* Rhabdomyolysis of gluteal muscles leading to renal failure: a potentially fatal complication of surgery in the morbidly obese. *Obes Surg* 2003; **13**: 302–5.
4. Lagandré S, Arnalsteen L, Vallet B, *et al.* Predictive factors for rhabdomyolysis after bariatric surgery. *Obes Surg* 2006; **16**: 1365–70.
5. Criddle LM. Rhabdomyolysis. Pathophysiology, recognition, and management. *Crit Care Nurs* 2003; **23**: 14–22, 24–6.
6. Sauret JM, Marinides G, Wang GK. Rhabdomyolysis. *Am Fam Physic* 2002; **65**: 907–12.
7. Lane R, Phillips M. Rhabdomyolysis. *BMJ* 2003; 327: 115–6.
8. Criner JA, Appelt M, Coker C, *et al.* Rhabdomyolysis: the hidden killer. *Medsurg Nurs* 2002; **11**: 138–43.
9. Sulowicz W, Walatek B, Sydor A, *et al.* Acute renal failure in patients with rhabdomyolysis. *Med Sci Monitor* 2002; **8**: 24–7.
10. Vanholder R, Sever M, Erek E, *et al.* Rhabdomyolysis. *J Am Soc Neph* 2000; **11**: 1553–61.
11. Zager RA. Rhabdomyolysis and myohemoglobinuric acute renal failure. *Kidney Int* 1996; **49**: 314–26.
12. Torres-Villalobos G, Kimura E, Mosquedo JL, *et al.* Pressure-induced rhabdomyolysis after bariatric surgery. *Obes Surg* 2003; **13**: 306–13.
13. Collier B, Goreja MA, Duke III BE. Postoperative rhabdomyolysis with bariatric surgery. *Obes Surg* 2003; **13**: 941–3.
14. Abassi A, Hoffman A, Better O. Acute renal failure complicating muscle crush injury. *Semin Nephrol* 1998; **18**: 558–65.
15. Cheney P. Early management and physiologic changes in crush syndrome. *Crit Care Nurs Q* 1994; **17**: 62–73.
16. Russel TA. Acute renal failure related to rhabdomyolysis: pathophysiology, diagnosis and collaborative management. *Nephrol Nurs J* 2000; **27**: 567–77.
17. Gronert GA. Cardiac arrest after succinylcholine: mortality greater with rhabdomyolysis than receptor upregulation. *Anesthes* 2001; **94**: 523–9.
18. Curry SC, Chang D, Connor D. Drug- and toxin-induced rhabdomyolysis. *Ann Emerg Med* 1989; **18**: 1068–84.
19. Haskins N. Rhabdomyolysis and acute renal failure in intensive care. *Nurs Crit Care* 1998; **3**: 283–8.
20. Slater MS, Mullins RJ. Rhabdomyolysis and myoglobinuric renal failure in trauma and surgical patients: a review. *J Am Coll Surg* 1998; **186**: 693–716.
21. Hollenstein U, Thalhammer F, Burgmann H. Disseminated intravascular coagulation (DIC) and rhabdomyolysis in fulminant varicella infection – case report and review of the literature. *Infection* 1998; **26**: 306–8.
22. Riggs JE, Schochet SS Jr, Parmar JP. Rhabdomyolysis with acute renal failure and disseminated intravascular coagulation: association with acetaminophen and ethanol. *Mil Med* 1996; **161**: 708–9.
23. Dayer-Berenson L. Rhabdomyolysis: a comprehensive guide. *Nephrol Nurs J* 1994; **21**: 15–8.
24. Gorecki PJ, Cottam D, Ger R, *et al.* Lower extremity compartment syndrome following a laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2002; **12**: 289–91.
25. Iseri C, Senkul T, Reddy PK. Major urologic surgery and rhabdomyolysis in two obese patients. *Int J Urol* 2003; **10**: 558–60.
26. Hofmann R, Stoller ML. Endoscopic and open stone surgery in morbidly obese patients. *J Urol* 1992; **148**: 1108–11.
27. Wiltshire JP, Custer T. Lumbar muscle rhabdomyolysis as a cause of acute renal failure after Roux-en-Y gastric bypass. *Obes Surg* 2003; **13**: 306–13.
28. Phillips PS, Haas RH. Statin myopathy as a metabolic muscle disease. *Expert Rev Cardiovasc Ther* 2008; **6**: 971–8.

29. Khurana RN, Baudendistel TE, Morgan EF, *et al*. Postoperative rhabdomyolysis following laparoscopic gastric bypass in the morbidly obese. *Arch Surg* 2004; **139**: 73–6.
30. Bocca G, van Moorselaar JA, Feitz WF, *et al*. Compartment syndrome, rhabdomyolysis and risk of acute renal failure as complications of the lithotomy position. *J Nephrol* 2002; **15**: 183–5.
31. Regan JP, Inabnet WB, Gagner M, *et al*. Early experience with two-stage laparoscopic Roux-en-Y gastric bypass as an alternative in the super-super-obese patient. *Obes Surg* 2003; **13**: 861–4.
32. Milone L, Strong V, Gagner M. Laparoscopic sleeve gastrectomy is superior to endoscopic intragastric balloon as a first stage procedure for super-obese patients (BMI ≥ 50). *Obes Surg* 2005; **15**: 612–7.
33. Polderman, KH. Acute renal failure and rhabdomyolysis. *Int J Artif Organs* 2004; **27**: 1030–3.
34. Kim KK. Exogenous causes of myoglobinuria – review of 26 cases. *J Korean Med Sci* 1996; **11**: 342–6.
35. Grover DS, Atta MG, Eustace JA, *et al*. Lack of clinical utility of urine myoglobin detection by microconcentrator ultrafiltration in the diagnosis of rhabdomyolysis. *Nephrol Dial Transplant* 2004; **19**: 2634–8.
36. Harriston S. A review of rhabdomyolysis. *Dimens Crit Care Nurs* 2004; **23**: 155–61.
37. Muckart DJ, Moodley M, Naidu AG, *et al*. Prediction of acute renal failure following soft-tissue injury using the venous bicarbonate concentration. *J Trauma* 1992; **33**: 813–7.
38. Al-Shekhlee A, Hachwi R, Jaberi MM, *et al*. The electromyographic features of acute rhabdomyolysis. *J Clin Neuromusc Dis* 2005; **6**: 114–8.
39. Carvalho DAF, Valezi AC, Brito EM, *et al*. Rhabdomyolysis after bariatric surgery. *Obes Surg* 2006; **16**: 740–44.
40. Lamminen AE, Hekali PE, Tiula E, *et al*. Acute rhabdomyolysis: evaluation with magnetic resonance imaging compared with computed tomography and ultrasonography. *Br J Radiol* 1989; **62**: 326–30.
41. Messing ML, Feinzimer ET, Brosnan JJ, *et al*. CT of rhabdomyolysis associated with malignant hyperthermia and seizures. *Clin Imaging* 1993; **17**: 258–9.
42. Russ PD, Dillingham M. Demonstration of CT hyperdensity in patients with acute renal failure associated with rhabdomyolysis. *J Comput Assist Tomogr* 1991; **15**: 458–63.
43. Steeds RP, Alexander PJ, Muthusamy R, *et al*. Sonography in the diagnosis of rhabdomyolysis. *J Clin Ultrasound* 1999; **27**: 531–3.
44. Nakahara K, Tanaka H, Masutani K, *et al*. The value of computed tomography and magnetic resonance imaging to diagnose rhabdomyolysis in acute renal failure. *Nephrol Dial Transplant* 1999; **14**: 1564–7.
45. Sharon GC. Rhabdomyolysis. *Orthop Nurs* 2005; **24**: 443–7.
46. Pasnik K, Krupa J, Stanowski E, *et al*. Successful treatment of gastric fistula following rhabdomyolysis after vertical banded gastroplasty. *Obes Surg* 2005; **15**: 428–30.
47. Better OS, Stein JH. Early management of shock and prophylaxis of acute renal failure in traumatic rhabdomyolysis. *N Engl J Med* 1990; **322**: 825–9.
48. Filis D, Daskalakis M, Askoxylakis I, *et al*. Rhabdomyolysis following laparoscopic gastric bypass. *Obes Surg* 2005; **15**: 1496–500.
49. Moghtader J, Brady WJ, Bonadio W. Exertional rhabdomyolysis in an adolescent athlete. *Pediatr Emerg Care* 1997; **13**: 382–5.
50. Sinert R, Kohl L, Rainone T, *et al*. Exercise-induced rhabdomyolysis. *Ann Emerg Med* 1994; **23**: 1301–6.
51. Singh D, Chander V, Chopra K. Rhabdomyolysis. *Methods Find Exp Clin Pharmacol* 2005; **27**: 39–48.
52. Slater MS, Mullins RJ. Rhabdomyolysis and myoglobinuric renal failure in trauma and surgical patients: a review. *J Am Coll Surg* 1998; **186**: 693–716.
53. Ron D, Taitelman U, Michaelson M, Bar-Joseph G, Bursztein S, Better OS. Prevention of acute renal failure in traumatic rhabdomyolysis. *Arch Intern Med* 1984; **144**: 277–80.
54. Wakabayashi Y, Kikuno T, Ohwada T, Kikawada R. Rapid fall in blood myoglobin in massive rhabdomyolysis and acute renal failure. *Intensive Care Med* 1994; **20**: 109–12.
55. Harper J. Rhabdomyolysis and myoglobinuric renal failure. *Crit Care Nurse* 1990; **10**: 32–6.
56. Ettinger JEMTM. *Rhabdomyolysis in morbidly obese submitted to open and laparoscopic gastric bypass* [PhD thesis]. Salvador, Brazil; Escola Bahiana de Medicina e Saúde Pública; 2007.
57. Ettinger JEMTM, dos Santos Filho PV, Azaro E, *et al*. Prevention of rhabdomyolysis in bariatric surgery. *Obes Surg* 2005; **15**: 874–9.
58. Ettinger JEMTM, Marcílio de Souza CA, Santos-Filho PV, *et al*. Rhabdomyolysis: Diagnosis and treatment in bariatric surgery. *Obes Surg* 2007; **17**: 525–32.

Chapter 19

Nursing considerations

Tracy Martinez

19.1 Introduction

Obesity is the greatest emerging public health crisis of our time, affecting millions of individuals worldwide. Because of this modern day epidemic it is fair to say that the number of inpatient admissions of MO patients will continue to increase, and that this increase justifies specialty training for nurses who are entrusted with the care of these patients. Postoperative complications will occur even following procedures by the most skilled surgeon. Failure by the nursing staff to recognize complications can lead to a delay in an appropriate and timely intervention, which in turn can contribute to the patient's demise. Therefore, it is imperative that the clinical nursing staff be educated and sufficiently trained to care for this patient population. Special training and clinical competencies include astute clinical assessment, recognition of complications, psychologic support, and patient physical safety and comfort. The goal of this chapter is to provide a guide for those caring for individuals of size during their hospital stay.

19.2 Nursing education and training

Peri-operative and medical/surgical nurse managers should provide in-depth education and training prior to assigning a nurse to this patient population. Topics for the initial nursing in-service should include:

- Pathophysiology of morbid obesity
- Medical co-morbidities associated with obesity
- Surgical treatment
- Clinical assessment
- Complication recognition and intervention
- Psychologic considerations.

Quarterly on-going education and in-service training should be offered for those identified as specialized bariatric nurses. These sessions may include:

- Case studies
- Current literature review
- Complication specific management
- Current trends
- Co-morbidity management
- Patient testimonials.

An additional educational opportunity to ensure optimum training is establishment of a bariatric nursing mentoring program. There are several ways to achieve a successful mentoring program. In our hospital nurses wishing to care for bariatric patients must attend the initial education presentation followed by training by an experienced bariatric nurse-mentor. The nurse in training is scheduled to work alongside their mentor, shadowing him or her for a three month period. This program insures that the trainee is exposed to many patients and to situations with the "back up" and support of an experienced bariatric nurse.

19.3 Implementing competencies

Beginning in the late 1980s, the then Joint Commission on the Accreditation of Healthcare Organizations (JCAHO) (now the Joint Commission) mandated that all nursing staff be assessed for competency. The components of competency include three critical domains. They are (a) *Cognitive skills* which means the ability to analyze and utilize critical thinking; (b) *Psychomotor skills* which demonstrate the ability to perform physical tasks necessary to do the job, in other words "technical skills" and lastly (c) *Interpersonal skills* which demonstrate the ability to work as an integral part of an interdisciplinary team [1].

Since competency assessment is the process of understanding an individual's potential knowledge and skills, competencies for bariatric nurses should address

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

the unique knowledge base (as outlined in 19.2) a nurse working with MO patients should possess.

Currently an increasing number of hospitals which perform bariatric surgery are implementing specific bariatric nursing competencies, a relatively new program to demonstrate the knowledge, skills and attitudes considered by the organization to be essential for the job of a bariatric nurse. There are several ways to assess competency and testing methods can vary. These include true/false test questions, multiple choice questions, and case studies with priority action questions.

19.4 Peri-operative nursing care

Nursing care after bariatric surgery entails all the routine post-operative assessment that a prudent skilled nurse would perform on any patient who has just undergone abdominal surgery. However, the bariatric nurse must even more carefully review each patient's history. The medical co-morbidities associated with obesity can increase the potential for complications and the need for diligent post-operative assessment [2].

Post-operative respiratory assessment of the MO patient is extremely important. Severe obesity, especially in the patient with obstructive sleep apnea (OSA), is associated with hypoventilation, with hypercapnia, decreased hemoglobin oxygen saturation, and daytime somnolence. Respiratory status can be further compromised by the effects of general anesthesia. Re-sedation is a real threat in the immediate post-operative period, especially among those patients with extreme obesity. By the evening of the first day of surgery, the effects of anesthetic agents should have dissipated. However, if the patient is using opioids pain medication, re-sedation can occur. When patient-controlled opioid analgesia is used, close observation is necessary.

The surgeon may order continuous positive-airway pressure (CPAP) for the OSA patient. Some surgeons are concerned that the pressurized oxygen will distend the gastric pouch and stress the anastomosis in patients who have undergone bariatric procedures and may not routinely order CPAP. For patients using CPAP, close post-operative observation with pulse oximetry and apnea monitoring is necessary.

Patients who are overweight should be positioned with the head of the bed elevated to 30% to maximize lung expansion. Incentive spirometry should be used in the hospital and continued at home to decrease the risk for atelectasis or pneumonia. Early and frequent ambulation by the patient will also reduce the incidence of respiratory complications.

Nurses and aides can also injure themselves lifting MO patients. Besides physical pain and incapacity, such injuries often result in lost work days. For the obese patient, mechanical patient lift equipment and other positioning devices, plus additional physical help, should be sought to prevent back injury.

Vigilant surveillance of signs and symptoms for surgical complications can have an enormous impact on overall outcome. Regardless of whether the procedure was by an open or laparoscopic approach, anastomotic leaks can be fatal if not recognized early. Anastomoses are often tested for leaks intra-operatively with air or methylene blue dye, but leaks can still occur post-operatively. Symptoms can be overt or subtle and can include abdominal tenderness, left shoulder pain, pain with swallowing, tachycardia, decreased urine output, fever, elevated white blood cell count, oxy-hemoglobin desaturation, or just a patient "not looking right", or complaining of a sense of impending doom.

Once a clinical assessment is made by the bariatric nurse, the surgeon must be notified immediately. The surgeon will decide whether to manage the leak by re-exploration and repair, or by placement of an abdominal drain by an interventional radiologist. In some cases, no intervention may be needed if the patient is hemodynamically stable.

Patients who suffer with obesity are at greater risk for lower extremity deep vein thrombosis (DVT) than normal weight surgical patients. Obesity is a major risk factor for the development of pulmonary embolism [3].

Prophylactic measures are necessary to minimize the risk of DVT and include administration of anticoagulant therapy pre-operatively and daily during the hospital stay. Anticoagulant therapy may be continued after discharge. Other preventative measures include sequential compression stockings during surgery and during hospital stay, and early and frequent ambulation. Patients should be educated on the importance of continued ambulation and activity (even after discharge) for continued DVT prevention. Some surgeons will consider placement of a vena cava filter before surgery for the higher-risk patient.

The importance of skin care and decubitus prevention is often misunderstood or minimized. Proper padding of pressure areas should be initiated and documented in the operating room. Some healthcare workers believe that because patients with obesity have "extra padding," they don't need padding protection.

Table 19.1 Signs and symptoms of serious early post-operative complications of the bariatric surgical patient

Pneumonia	**Pulmonary embolism**
Fever	Dyspnea
Increased sputum production, cough	Tachypnea
Shortness of breath	Chest pain, pleuritic pain
Positive sputum culture	Tachycardia
Positive chest x-ray	Hemoptysis
	Cardiac arrhythmia
	Patient feels impending doom
Hemorrhage	**GI leak**
Tachycardia	Tachycardia
Hypotension	Tachypnea
Increased drain output, frank blood	Left shoulder pain
Decreased urinary output	Abdominal tenderness
Decreased hemoglobin and hematocrit	Pain after drinking
Increased respirations	Hiccups
Clammy skin	Hypotension
	Oliguria
	Increased white blood cell count
	Fever
	Increased blood sugar
	Patient feels impending doom
Bowel obstruction	**Rhabdomyolysis**
Abdominal pain	Severe muscle pain in backside
Abdominal distension	Elevated serum creatine
Decreasing bowel sounds	Brown pigment in urine
Vomiting	
Myocardial infarction	**DVT**
Substernal chest / jaw pain	Swollen extremity
Abnormal ECG	Leg pain
Sweating	Abnormal Doppler flow studies
Nausea	
Dyspnea	
Hypotension	
Elevated enzymes creatine phosphokinase & troponin	

Any signs or symptom should raise suspicion and consideration for interventions.

Nothing could be further from the truth. Patients who suffer with MO are at greater risk for skin breakdown and infection because of excess weight on bony prominences and less blood supply to the distal subcutaneous tissue [4]. If a patient has diabetes, the risk of ulcers is further increased. Early ambulation, proper hydration, and thorough skin assessment help reduce the risk for skin breakdown and infection.

Rhabdomyolysis can occur following surgery in MO patients. Muscle destruction can occur due to the pressure phenomenon during prolonged surgery. Life threatening symptoms of rhabdomyolysis include those listed in Table 19.1. Rapid diagnosis and intervention is imperative [5].

19.5 Nutritional support

It is important that the nursing staff understand the patient's complete clinical and medical history to ensure appropriate nutritional support. Obese patients may be admitted with various diagnoses, and the physician's orders will be written accordingly. For example, besides being post-surgical is the patient also diabetic, does he or she have cardiac disease, did they undergo bariatric surgery, which procedure, and when? If the patient has a pertinent medical history, the nurse should ensure the orders reflect the medical condition.

The role of the dietician is an important and vital component in the bariatric team since nutrition assessment and appropriate dietary management have been shown to be an important correlate with success. If the patient is an acute post-operative bariatric patient or had bariatric surgery in the past, specific nutrition guidelines should be considered.

Immediately after bariatric surgery, no matter which surgical procedure they have had, patients are commonly placed on a sugar-free, clear liquid diet advancing to sugar-free, full liquid diet for a week or more. Routinely, the dietary progression is clear liquids, advancing to a pureed texture, followed by mechanical soft diet. Since stomach volume is decreased, small slow sips of fluid should be encouraged. It is important that the nurse not over encourage the patient's intake, keeping in mind the stomach capacity is significantly reduced following most bariatric procedures. Gastric banding patients do not have significant volume restriction immediately post-operatively since adjustments do not begin until 6 weeks after the band is implanted.

It's important that the nurses and dieticians responsible for the bariatric patient understand which

procedure was performed and what anatomic changes have occurred. Many falsely believe that overweight patients are in good nutritional health. On the contrary, obese patients are commonly undernourished, protein deficient and lacking in essential nutrients necessary for healing [6]. Thoughtful eating behavior needs to be reinforced. Behavior changes include drinking and eating slowly, chewing very thoroughly, and limiting meal volume. For most procedures, the patient's anatomic gastric volume is reduced to just a small fraction of what it was prior to surgery. After gastric bypass, for example, patients can use the analogy of a golf ball to visualize their newly formed pouch. It is important to stress that the patient eat only until their hunger subsides; this is called satiety. Over eating will promote vomiting and can potentially stretch the pouch over time.

Patients with purely restrictive procedures, such as gastric banding and vertical ring gastroplasty, should be encouraged to limit their eating to no more than three meals a day. Snacking can be the saboteur of the surgery once there is no "sensation of fullness" feedback. Patients should be encouraged to eat lean proteins and vegetables while staying away from fibrous meats, pasta, rice, and other simple carbohydrates as well as high sugar fluids and foods. Abstaining from fluids at mealtimes can promote the feeling of satiety longer. Eating lean proteins first and possibly daily protein supplements can help ensure adequate protein intake during weight loss as well as promoting satiety. A high potency multivitamin containing vitamin B_{12}, B_6 and 400 mg of folic acid is recommended for all patients. Iron should be considered for menstruating women [7].

Roux-en-Y gastric bypass is both a restrictive and malabsorptive procedure. Due to the malabsorption created by bypassing the distal stomach and duodenum, vitamin B_{12}, iron and calcium need to be supplemented. Calcium should be in the form of calcium citrate and iron in the form of ferrous fumerate [8].

Biliopancreatic diversion and biliopancreatic diversion with duodenal switch are malabsorptive procedures which are performed less commonly in the United States than in Europe. Following these procedures multiple bowel movements may occur daily. Weight loss after these procedures is thought to occur through the malabsorption of macronutrients. Serum levels of vitamins A, D, E, and K and zinc can also be affected when absorption is impaired. Supplementation of these nutrients is required for optimum health. Water soluble forms of the fat soluble vitamins are necessary.

Adequate protein is essential during rapid weight loss following bariatric surgery to protect lean muscle mass. Clinical experts recommend up to 70 g day^{-1} during weight loss without complications. Due to the limited volume capacity many patients supplement with a liquid protein to meet the daily protein requirement.

Thiamine (B_1) deficiency can be significant and a delayed diagnosis can have devastating consequences. Thiamine is stored in the body for a relatively short time of 9–18 days. Nurses should consider a thiamine deficiency after prolonged periods of vomiting. Beriberi is a thiamine deficiency that affects numerous organs including the peripheral and central nervous systems. The window of opportunity for diagnosis and treatment is narrow. If treatment is delayed, irreversible neuro-muscular disorders can occur (Wernicke encephalopathy).

Symptoms of thiamine deficiency include nystagmus, ataxia, memory loss, progressive paralysis, coma, and death. If thiamine deficiency is suspected, immediate administration of 100mg of thiamine IV is indicated with continuing 100 mg thiamine every 8 hours until symptoms resolve. Intramuscular injection of 100 mg thiamine may be administered if intravenous access is not possible. It is important not to administer IV dextrose to a patient with known or suspected thiamine deficiency because dextrose can further deplete thiamine stores.

19.6 Empathy training and psychologic support

Hospital caregivers assuming responsibility for MO patients should attend an empathy training course. Common biases in healthcare workers' attitudes toward obesity are prejudice and discrimination. Prejudice is described as a pre-judgment, and arguably most people carry some form of pre-judgment toward a particular category of individuals or group. Discrimination refers to behavior based on this pre-judgment. Overweight Americans experience both [9].

Healthcare workers, like society at large, often feel that if patients ate less and exercised more they wouldn't suffer with obesity. Obesity is a multi-factorial disease that has strong genetic, complex hormonal and metabolic components. In a survey of nursing attitudes toward people who suffer with obesity, nurses reported beliefs that these individuals are likely to have issues

Table 19.2 Creating an obesity-safe environment–equipment and facility concerns

Lobby	Admitting
Empathetic and weight-safe/ wide seating	Armless/wide, weight-safe chairs
Handicap restrooms	Wide wheelchairs
Operating room	**Dedicated unit**
Weight-safe/wide OR tables	Bariatric beds (appropriate width and weight)
Dedicated long instruments and trays	Floor mounted toilets and guardrails
Transfer devices	Scales for weight limits (500 lb)
Special intubation cart	Wide showers with guardrails and seats
Large blood pressure cuffs	Large patient gowns
Large sequential compression sleeves	Weight safe furniture
	Wide walkers, gurneys, lift and transfer devices
Radiology	**Clinic/Office**
All equipment weight-safe	Wide seating that is weight-safe
	High weight scales (500 lb)
	Large exam patient gowns
	Floor mounted toilets with guardrails
	Large blood pressure cuffs

Note: All weight bearing equipment and furniture should be weight rated to at least 500 pounds. Manufacturers specification documentation should be accessible to staff.

with anger, are lazy, and over-indulgent [10]. The problem is obvious, unless empathy training is mandated, patients are at risk of discrimination in a place where caring should be uncompromised.

Empathy training should include recognition of the prevalence of discrimination, the factors contributing to obesity, and most importantly effective ways to convey empathy. Making comments to patients, no matter how positively stated, can be insulting and hurtful. For example: "you will be so beautiful when you lose weight", or "you have such a beautiful face" should never be said.

Patients who suffer from MO do not want to bring attention to their size. The nurse should be aware that the patient may not ask for help when they need it, or make requests for other special needs.

Supportive measures should include eye contact, touching patient's arms, and conveying a non-judgmental attitude when caring for these patients who commonly have endured a lifetime of discrimination. These simple acts can make an enormous emotional difference to the individual who suffers from this misunderstood disease.

19.7 Special needs and equipment

Any institution that assumes care for MO patients must also provide an environment to ensure their safety. An effective practice to help clinicians understand the physical challenges patients must endure on a daily basis is to try to visualize patients environment as if you yourself were 100 pounds heavier. That world looks very different, challenging, and frightening. Every effort should be made to provide empathetic, safe, and dignified care. Awareness and responsiveness to special needs are important. Trace all the steps a patient of size may experience in the hospital. Is there adequate and safe seating, beds, handicapped restrooms, and other equipment for transferring a MO patient? A good practice is to periodically check the environment for any changes that may have inadvertently occurred. This can help prevent an unsafe and liability event. An inventory of hospital equipment with the manufacturer's specifications listing weight limits should be available in all hospital units.

19.8 Conclusion

The experience of caring for a MO patient can be both challenging and rewarding. Both from a medical and psychologic perspective these patients are complex so it is important that the nurses caring for them have the education, expertise, and understanding necessary to provide optimal care. Treating this population with competence, safety, and compassion can make a significant difference to the patient's hospital experience. Many nurses, including this author, believe that patients who suffer from MO are among the most rewarding and appreciative individuals to care for.

References

1. D 'Alfonso J. Designing competencies that count. Certified Boards, Inc. 2004.
2. Graling P, Elariny H. Perioperative care of the patient with morbid obesity. *Obes Res* 2003; **11**: 496–506.
3. Roop K, Aboussouan L, Auckley D, *et al*. Challenges in pulmonary risk assessment and perioperative management in bariatric surgery patients. *Obes Surg* 2008; **18**: 134–8.

4. Gruendemann BJ, Mangum SS. *Infection prevention in the surgical setting*. Philadelphia: Saunders; 2001.
5. DiRocco D, Halverson J, Planer J, *et al*. Post operative care of the bariatric patient. In: Buchwald H, Cowan G, Pories W, eds. *Surgical Management of Obesity*. Saunders Elsevier, 2007; 131–8.
6. Hahler B. Morbid obesity: A nursing care challenge. *Medsurg Nurs* 2002; **11**: 85–90.
7. Dixon J, O'Brien P. Nutritional outcomes of bariatric surgery. In: Buchwald H, Cowan G, Pories W, eds. *Surgical management of obesity*. Saunders Elsevier 2007; 357–63.
8. Aills L, Blankership J, Buffington C, *et al*. ASMBS Bariatric Surgery Perioperative Guidelines. Surg for Obes and Relat Diseases. July/Aug 2008 Supplement Vol **4**.
9. Gallagher S. Sensitivity in: *The challenges of caring for the obese patient*: Edgemont, PA: Matrix Medical Communications, 2005; 93–8.
10. Maroney D, Golub S. Nurses attitudes toward obese persons and certain ethnic groups. *Percept Mot Skills* 1992; **75**: 387–91.

Chapter 20

Long-term complications following surgery

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20.1 Introduction

Obesity is associated with numerous medical comorbidities, which place patients at greater risk of perioperative complications. MO patients undergoing surgery generally have lower physiologic reserve and may not manifest the typical signs of early complications, including fever, pain, or abnormal laboratory values. Physical findings may also be masked. Long-term complications, defined as events developing more than 1 month following surgery, are not uncommon. Such complications range from minor to severe, and can be self-resolving or can require reoperation. Correct and timely diagnosis and management of complications are critical to successful outcomes, such as ensuring good quality of life and optimizing weight loss.

As there are little data available regarding long-term surgical complications in the obese surgical population in general, this overview will focus mainly on bariatric surgery patients. We will consider the late complications following the most commonly performed procedures: Roux en Y gastric bypass (RYGB), laparoscopic adjustable gastric band (LAGB), vertical-banded gastroplasty, and biliopancreatic diversion (BPD). There are two general categories of bariatric surgery: malabsorptive and restrictive procedures. Malabsorptive procedures (e.g., BPD) involve surgically bypassing a portion of the gastrointestinal (GI) tract to decrease the absorption of fat and calories. Restrictive procedures (LAGB and VBG) rely on creating a smaller gastric pouch to reduce oral intake by early satiety. Roux en Y gastric bypass combines both malabsorption and restriction as a small gastric pouch is created with a relatively small outlet, which is connected to intestines that bypass the upper biliary and pancreatic tract. Roux en Y gastric bypass also appears to alter neurologic and gastric peptides that control satiety, which contributes to the subsequent weight loss.

The common complications that are shared by all bariatric procedures will be discussed first, including incisional hernia, bowel obstruction and internal hernia, symptomatic gallstones, and mortality. Specific problems that may arise due to the unique technical aspects of the operations will follow. For malabsorptive and combined procedures, a major long-term concern is nutritional deficiencies. Specific complications of RYGB include dumping syndrome, marginal ulcer, staple-line disruption and gastric fistula, anastomotic stricture, and gastric remnant dilatation. For LAGB we review slippage, stomal stenosis, band erosion, port complications, and esophageal and pouch dilatation. Late surgical complications particular to obese patients undergoing non-bariatric surgery will also be discussed. Understanding these types of complications, why they occur, how frequently they develop, and how they are managed, will help the team of physicians who care for these patients, both before and after surgery.

20.2 General complications

20.2.1 Incisional hernia

Incisional hernias are a potential complication of most operations. Incisional hernias in obese patients have been reported at an incidence of up to 15% following laparotomy, two times higher than that seen in the overall study population [1]. Since obesity itself is a risk factor, it is no surprise that incisional hernias are common after bariatric procedures, and the rate varies by the type of surgery. This complication occurs with an incidence of 8.5% after open RYGB [2]. As expected, hernias occur less often after laparoscopic surgery as the incision lengths are small. A hernia incidence rate of 0.5% is reported after laparoscopic RYGB [2], and when they do occur they tend to develop at the larger (>10 mm) trocar site. The majority of incisional hernias after

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LAGB tend to occur only after conversion to laparotomy, at rates (9%) similar to those of open RYGB [3].

Signs of incisional hernias include vague abdominal discomfort and bulging or protrusion of abdominal contents at an incision site. Surgical repair, which is usually performed laparoscopically with mesh, should ideally be delayed until maximal weight loss has occurred, decreasing the risk for recurrence. Incarceration and bowel obstruction occur rarely as a result of incisional hernia, but require immediate surgical attention. Elective hernia repair can be performed simultaneously with plastic surgery contouring procedures such as abdominoplasty. The potential for this complication increases the long-term follow-up and cost of care for patients who have undergone bariatric surgery.

20.2.2 Bowel obstruction

Nausea and vomiting are not uncommon complications after bariatric surgery. It generally takes patients some time to adjust to eating smaller portion sizes. Eating too fast or too much at one sitting, or not chewing food properly, can cause a sense of fullness and epigastric pain. Medications can also get stuck in the esophagus or at the gastric outlet. The work-up includes instructing the patient to keep a food diary to help differentiate between difficulty with solids or liquids. In the case of the former, improving eating mechanics (e.g., smaller meals and more chewing) may alleviate symptoms. Vertical-banded gastroplasty has a high incidence of persistent (> 10 years) vomiting (20%) and heartburn (16%) [4]. In severe cases, treatment may require conversion to RYGB [5].

In general, lack of resolution of these symptoms must prompt an investigation to rule out intestinal obstruction. Small bowel obstruction (SBO) is a significant morbidity that can occur after any abdominal surgery. The causes of SBO after bariatric surgery include adhesions, internal or incisional hernia, intussusception, volvulus, and problems related to the intestinal anastomosis. The most common cause of SBO after open bariatric procedures is adhesions [6].

The overall rate of bowel obstruction after RYGB is reported to be between 2 and 8%, and appears to be higher after laparoscopic procedures [10]. This is due to a higher incidence of internal hernias, caused by a loop of bowel becoming entrapped. During the early stages of the learning curve for RYGB procedures, surgeons did not routinely close the mesenteric defect and Peterson's space (between the mesocolon and the mesentery of the small intestine), allowing the hernias to occur. The herniated bowel loop, which usually includes the Roux limb, can volvulize and become strangulated, forming a closed loop obstruction. The rate of internal hernias has decreased as surgeons now tend to close these spaces where the bowel can potentially herniate. This complication now occurs more commonly after laparoscopic procedures because fewer adhesions are formed, and some surgeons do not close the mesenteric defect using non-absorbable sutures.

The symptoms of an internal hernia include cramping abdominal pain often occurring 10–30 min after eating. The diagnosis can be made with a CT scan, which demonstrates dilated small bowel loops and a transition point adjacent to the jejunojejunostomy. However, up to 20% of internal hernias may be missed by radiographic studies [20]. If symptoms persist a diagnostic laparoscopy may be necessary to make the diagnosis, at which time the herniated bowel can be reduced and the hernia space can be closed with sutures. General symptoms of bowel obstruction include nausea and vomiting, abdominal pain and distention, and obstipation (inability to pass flatus or have a bowel movement). Physical signs may consist of high-pitched or a paucity of bowel sounds, as well as a spectrum of abdominal pain with palpation ranging from mild to frank signs of peritonitis. Conservative treatment with bowel rest and nasogastric suctioning is generally attempted first. However if symptoms fail to resolve or there are any signs of ischemic bowel, surgical repair is generally required to relieve the obstruction and resect any segment of non-viable bowel.

20.2.3 Symptomatic gallstones

Another common complication after the significant weight loss following bariatric surgery is the development of gallstones. The switch to low-calorie meals that occurs especially after malabsorptive procedures promotes gallbladder stasis and decreases the bile salt pool. The risk is highest during the period of rapid weight loss, and decreases once weight has stabilized (generally by 24 months). Gallstones after bariatric surgery occur at an incidence of 22–71%, with up to half of patients developing symptomatic cholelithiasis [7, 8]. The clinical presentation includes post-prandial right upper quadrant abdominal pain radiating to the back or shoulder that begins 1–3 hours after eating, and may be associated with nausea or vomiting. The diagnosis includes the typical symptoms in association with an abdominal ultrasound examination that demonstrates gallstones. In the event of acute cholecystitis, signs may also include fever and an elevated white blood cell count.

To prevent the potential need for another abdominal operation, it is generally recommended to perform a simultaneous cholecystectomy on patients with symptomatic gallstones undergoing open bariatric surgery. Recent evidence has also suggested that ursodeoxycholic acid, a bile acid that can dissolve gallstones by decreasing bile cholesterol secretion and increasing the solubility of cholesterol in bile, can prevent gallstone formation after bariatric surgery [9]. It has been used at a dose of 600 mg daily for the initial 6 month period after surgery in clinical trials, and has decreased the rate of gallstone formation by up to 30% [10]. However the costs and potential side-effects (mainly nausea and diarrhea) limit patient compliance with this regimen.

20.2.4 Mortality

The rate of late mortality attributed to bariatric surgery is generally quite low. The causes include pulmonary embolus, cardiac events, and gastrointestinal leak. The mortality between 30 days and 1 year ranges between 0.1 and 4.6%, with the majority of deaths occurring after malabsorptive rather than restrictive procedures [12]. The difference in mortality is largely due to the greater technical demand of malabsorptive procedures, which require transection of the GI tract and construction of anastomosis. In a sample of Medicare patients over 65 years old, the 1-year mortality following bariatric surgery was as high as 11%; however, surgical and hospital volume mitigates mortality risk [13]. Besides age, risk factors for death include male sex (14), superobese condition (BMI $\geq 50\ kg\ m^{-2}$) [15], and diabetes [16].

The above-mentioned mortality rate includes all causes of death, which may not be directly related to the surgery. Long-term all cause mortality in the obese population has actually been shown to decrease by as much as 40% following bariatric surgery [17]. This and similar studies are all limited in design to answer the long-term mortality question, as the comparison group has inherent biases in that they did not seek and were not offered surgery, leading to possible differences in co-morbidities and lifestyle changes. They do suggest that bariatric surgery patients may have a 56% decrease in coronary artery disease related deaths, 92% decrease in diabetes related deaths, and a 60% decrease in cancer-related deaths. However, the rate of non-disease related mortality (including suicide, accidents, and others) has been found to be up to 1.6 times higher after surgery.

20.3 Malabsorptive and combined procedures

20.3.1 Nutritional deficiency

Early satiety and difficulty digesting certain foods (especially meat) can limit the consumption of nutrients after bariatric surgery. Irrespective of dietary adjustments, changes in the GI tract following malabsorptive procedures frequently result in vitamin deficiencies. The most prevalent deficiencies occur in iron and vitamin B_{12}, followed by zinc, folate, vitamin D, and calcium. Other vitamins absorbed in the duodenum and proximal jejunum that are affected by exclusion of the proximal GI tract include copper, thiamine, riboflavin, niacin, pyridoxine, and calcium.

Iron is absorbed in the duodenum, and therefore bypassing this segment of small bowel frequently causes deficiency. In addition to direct malabsorption, the conversion of ingested ferric iron to absorbable ferrous iron is impaired due to the absence of gastric acid, which is normally excreted by the distal stomach. Iron deficiency is especially common in menstruating women. The development of gastritis, esophagitis, or a marginal ulcer can also cause induce iron deficiency [18]. Vitamin B_{12} metabolism is disturbed at several steps after the surgery. The exclusion of the distal stomach limits the binding of B_{12} to intrinsic factor, which is secreted by gastric parietal cells and is essential to B_{12} absorption in the ileum. Decreased exposure of food to the bypassed stomach impairs the release of vitamin B_{12} from food.

Zinc deficiency can present with hair loss, while thiamine deficiency can cause limb weakness, unsteady gait, diplopia, confusion, and even Wernicke's encephalopathy. Folate can be absorbed anywhere in the GI tract, so its deficiency is usually caused by poor oral intake rather than malabsorption. Vitamin D deficiency can also occur due to the gastroenterostomy. Calcium is similarly malabsorbed because the proximal duodenum is bypassed. Daily supplementation with 1200 mg of calcium is essential to prevent hypocalcemia and osteoporosis.

Deficiencies of iron, folate, or vitamin B_{12} are all common causes of anemia after gastric bypass. Symptoms include fatigue, dyspnea, and muscle weakness. Severe iron deficiency can also present with pica and oral discomfort, while severe B_{12} deficiency can cause paresthesias and ataxia. Prevention of these vitamin deficits is not reliably achieved with a daily

multivitamin. A high index of suspicion with serum levels checked as necessary is therefore critical, especially as B_{12} deficiency frequently does not show up for months or even years. Treatment in mild cases consists of oral or in severe cases parenteral iron replacement.

Protein calorie malnutrition can also occur, especially after biliopancreatic diversion with a duodenal switch (PBDS). Laboratory values will reveal a low serum albumin and phosphate. Poor oral protein intake may be caused by nausea or vomiting, and mild deficiency can be corrected by protein supplementation. Severe deficiency caused by malabsorption requires surgical revision, often with converting a long-limb bypass (which is frequently performed in the super-obese to divert a longer intestinal segment from the functional GI tract) to a standard bypass [6].

20.3.2 Gastric bypass

20.3.2.1 Dumping syndrome

Alterations in gastric anatomy, especially those that involve the pyloric sphincter, can cause rapid gastric emptying. This can produce a constellation of symptoms referred to as the *dumping syndrome*, which involves lightheadedness, dizziness, abdominal pain, bloating, and diarrhea. Early dumping (30–45 minutes after a meal) occurs due to a shift of intravascular fluid into the bowel lumen, causing dehydration and an acute increase in bowel luminal volume. Late dumping (2–4 hours after a meal) involves reactive hypoglycemia due to a continued insulin effect past the duration of the peak post-prandial glucose level. This is not always considered a complication, as it encourages patients to avoid consuming large carbohydrate loads. Rarely the symptoms can become debilitating, and a small number of patients have been determined to have beta cell hyperplasia (termed nesidioblastosis) [19].

20.3.2.2 Marginal ulcer

Another well-recognized complication following RYGB is marginal ulceration (also referred to as an anastomotic or stomal ulcer). This develops in the jejunal mucosa at the gastrojejunal anastomosis. The reported incidence varies widely from 1 to 16% [20]. Medical risk factors include smoking, alcohol, and the use of non-steroidal anti-inflammatory drugs (NSAIDs). It has been postulated that *Helicobacter pylori* may also be a factor, but its exact role is unknown (21). Patients screened, and when positive treated, for *H. pylori* pre-operatively were found to have an almost three times lower incidence of marginal ulcers at 3 years [22]. Surgical sources include mucosal ischemia, a retained foreign body (i.e., non-absorbable sutures or staples), and a gastrogastric fistula, which can cause reflux of acid from the gastric remnant to the small gastric pouch.

Symptoms are similar to those of a standard peptic ulcer and include vague abdominal pain, nausea or vomiting, and occasionally GI bleeding. Dysphagia to both solids and liquids may also be present. The work-up includes endoscopy or an upper GI gastrografin study. These can help to distinguish an ulcer from an anastomotic stricture, which can have similar presenting symptoms. Once the diagnosis is established, conservative treatment consists of avoidance of NSAIDs, a course of antacid medication generally with proton pump inhibitors (PPIs), and if indicated triple therapy for *H. pylori*. The presence of a gastrogastric fistula generally also requires surgical repair. Untreated marginal ulcers can lead to anastomotic strictures and gastric outlet obstruction. Intractable ulcers, especially if surgically caused (e.g., retained foreign body, or tension and ischemia of the anastomosis), may require operative resection of the ulcer and revision of the gastrojejunostomy to eliminate tension.

20.3.2.3 Staple-line disruption/gastrogastric fistula

Roux-en-Y gastric bypass includes division of the stomach to create a small proximal pouch, restricting the amount of food that can be consumed at one time. In the past, this operation was performed simply with staple partitioning. As a result, there was a 12% incidence of staple-line dehiscence, allowing the patient to eat without discomfort and leading to regaining of weight [23].

The operation was subsequently amended to completely divide the stomach, with the goal of eliminating weight regain due to staple-line dehiscence. However, late staple-line failure can still occur if the pouch remains close to the gastric remnant. The likely catalyst is an enteric leak with abscess formation adjacent to the staple line, which drains down into the distal stomach. This creates a communication between the proximal gastric pouch and the distal gastric remnant referred to as a gastrogastric fistula, which occurs with an incidence of 3% [24]. A gastric leak usually presents early with systemic symptoms and presents the need for reoperation. However, the development of a fistula allows for internal drainage, delaying symptoms. Incomplete division of the stomach during the original operation can also cause this complication, as can

patient non-compliance with small meals with resultant gastric pouch distention and tension placed on the staple line. In the absence of a leak or sepsis, surgical intervention is not required [25]. However, the presence of an uncorrected fistula increases the risk of a marginal ulcer and negates the weight loss produced by the surgery.

Once symptomatic, gastrogastric fistulas can present with signs of sepsis (fever, tachycardia, elevated white blood cell count) as well as abdominal pain, distention, and nausea or vomiting. They can be diagnosed by an upper GI barium contrast study or abdominal CT scan. Treatment consists of open or laparoscopic repair of the fistula, frequently a difficult operation due to adhesions from the original bariatric surgery.

20.3.2.4 Anastomotic stricture

Partial obstructions can occur at intestinal anastomosis sites (i.e., gastrojejunostomy or gastrogastrostomy) and are referred to as stomal stenosis or strictures. Strictures usually occur at the anastomosis between the stomach and the jejunum (gastrojejunal) rather than at the intestinal (jejunojejunal) anastomosis. The incidence of the former is 3–9% after RYGB compared to a 0.8% incidence of jejunojejunal strictures [26, 27]. Potential causes include ischemia, excessive scar formation, and gastric acid hypersecretion. Late strictures can occur from months to years after surgery and are usually caused by adhesions.

Symptoms include dysphagia, nausea or vomiting, and abdominal pain. Dysphagia is generally greater to solids than to liquids and is more severe than that caused by a marginal ulcer. Epigastric pain usually occurs almost immediately after eating. Intestinal strictures can also cause diffuse abdominal pain secondary to dilatation of the afferent limb. The diagnosis can be made by fluoroscopy or CT scan. Endoscopic balloon dilation is the first-line treatment and though multiple therapeutic endoscopies may be required, it is rare that a surgical intervention is required to treat a stricture [28]. Serial dilations also decrease the risk of gastric perforation, a risk that must be considered along with the potential to diminish the restrictive effect of the bariatric procedure.

20.3.2.5 Gastric remnant dilatation

Obstruction of the loop of bowel that drains the biliary system (referred to as the biliopancreatic limb) can occur due to anastomotic stenosis or kinking, causing acute dilatation of the gastric remnant. This is a rare complication that occurs at an incidence of 0.6% [29]. The gastric remnant can become acutely dilated and even perforate. Symptoms include severe epigastric pain, hiccups, and abdominal distention, and can progress to obstructive jaundice and hemodynamic instability. Emergency treatment consists of percutaneous gastrostomy tube decompression, followed by definitive repair of the underlying obstruction (Table 20.1).

20.4 Gastric banding

The major complications following LAGB include band slippage or erosion, gastric prolapse, port/tubing malfunction, pouch/esophageal dilation, esophagitis and infection. A trial conducted by the Federal Drug Administration (FDA) shortly after the approval of LAGB demonstrated that by 3 years post-operatively, 76% of patients had experienced at least one adverse event [30]. In addition, one third of patients required removal of the band, most commonly due to complications or inadequate weight loss. Of note, the rate of complications other than infection is much lower for surgeons with greater experience. In support of these conclusions, subsequent studies were conducted which found similar rates of complications and removal. A 2007 review of two multicenter prospective, single-arm surgical trials evaluating 485 patients who underwent laparoscopic placement of a gastric band from 1995 and 2001 again found 66–76% of patients experiencing complications and one third requiring the removal of their band [31].

20.4.1 Band slippage

Band slippage is one of the most common complications following LAGB, with an incidence of up to 24% seen in the initial FDA trial. However, more recently reported rates have decreased significantly to 2–14% [32, 33]. This is in large part due to newer techniques which prevent direct exposure of the stomach wall to the band [34]. Early LAGB placement was performed according to the perigastric technique. This involved a perigastric placement of the band, achieved by measuring a fixed distance down from the gastroesophageal junction and then dissecting the route for the band next to the gastric wall. Later techniques are referred to as the pars flaccida technique. This involves a higher placement of the band through the pars flaccida, leaving the gastric neurovascular bundle intact on the wall of the stomach, involving a simpler dissection and a much smaller gastric pouch.

Table 20.1 Incidence of common gastric bypass complications

Study	MacLean 2000 [46]	White 2005 [47]	Capella 2007 [48]	Schauer 2000 [49]	Higa 2001 [50]	Suter 2006 [51]
No. patients	243	342	1180	275	1500	466
Follow-up (months)	65	48.6	12[a]	9.4	36	28
Procedure	Open	Open	Open	Lap	Lap	Lap
Reoperation	–	14.0%	–	–	1.1%	4.1%
Bowel obstruction[b]	2%	0.6%	0.5–1%	0.3%	2.7%	1.8%
Internal hernia	–	–	–	–	2.5%	0.9%
Adhesions	–	–	–	0.3%	0.2%	0.9%
Incisional hernia	16%[b]	6.7%	1–4.3%	0.6%	0.3%	1.3%
Symptomatic gallstones	24%	6.7%	–	1.5%	2.1%[b]	–
Anastomosis	2%	19.5%	1.3–3%	6.1%	6.4%	6.4%
Staple-line disruption	–	9.6%	–	–	0.7%	–
Ulcer	–	6.4%	0.5–2%	4.7%	0.8%	0.6%
Anastomotic stenosis	–	3.5%	0.5%	0.7%	4.9%	5.8%
Gastric fistula	2%	–	0.5%	0.7%	–	–
Nutritional deficiency	–	–	–	[c]		[d]
Iron				9.8%		18.2%
Vitamin B_{12}						44%
Folic acid						10.9%
Hyperparathyroidism						32.4%
Anemia				8%		13.5%

[a] Not explicitly stated.
[b] Operated on.
[c] Multivitamin supplementation started at 1 month post-surgery. Blood samples used to measure nutrition levels.
[d] Blood samples used to measure levels.
Lap, laparoscopic procedure; Open, open procedure.

Correct positioning of the band is crucial to provide restriction of the stomach, thereby limiting food intake. If the band slips, the restrictive force is eliminated and the surgery is ineffective. Slippage of the band can occur anteriorly, posteriorly, or concentrically. The diagnosis is made radiographically. On abdominal x-ray, the band will appear horizontal if the gastric wall slips anteriorly and vertical if the wall slips posteriorly. Due to the partial gastric obstruction created when the band slips, patients present with food intolerance, epigastric pain, and acid reflux. Initial treatment is to evacuate the saline from the band. If this fails to relieve the obstruction and return the band to its original position, the next step is to surgically attempt repair and/or replacement of the band. Unfortunately this frequently fails and symptoms recur, obviating the need for further laparoscopic or open revision of the banding procedure.

20.4.2 Stomal stenosis

Late stomal stenosis can occur after laparoscopic band placement. It can also occur after VBG though usually at a later time-point, with an incidence of up to 10% [35]. The causes include gastric inflammation with mucosal thickening and iatrogenic overinflation of the band. Injection of hyperosmolar contrast into the band can also cause this complication. Obstructive symptoms typically come on gradually, and treatment can often be conservative with endoscopic dilatation.

20.4.3 Band erosion

Band erosion is a much more infrequent complication with an estimated frequency of 0.6–1% [36]. It is thought to occur from either an excessively tight band, causing gastric wall ischemia or mechanical trauma related to the band buckle. This complication should be suspected when the patient suddenly experiences

Table 20.2 Incidence of laparoscopic adjustable gastric band complications

Study	Belachew 2002 [52]	Zinzindohoue 2003 [53]	Mittermair 2003 [54]	Weiner 2003 [55]	Angrisani 2003 [39]	Parikh 2005 [56]
No. patients	763	500	454	984	1863	749
Follow-up (months)	> 48	13	30	55	72	36[a]
Reoperation	11.1%	17%	7.9%	3.9%	4.9%	10.7%
Band removal	3.1%	10.4%	–	0.9%	1.1%	1.5%
Replacement/ revision	8%	6.6%	7.9%	1.4%	1.0%	6.1%
Band slippage/ migration	0.9%	11%	5.5%	3.7%	0.1%	0.2%
Band leakage	–	–	3.1%	–	–	–
Band rupture	0.9%	11%	2.4%	0.1%	0.1%	0.1%
Port/tubing[b]	2.5%	7.2%	7.3%	4.5%	4.1%	2.4%
Gastric[c]	–	0.6%	2.2%	–	6.1%	4.9%
Pouch dilatation	–	0.4%	2.2%	–	4.9%	2.0%
Esophageal dilation	–	0.8%	–	2.4%	–	0.3%
Symptomatic gallstones	–	–	–	10.7%	–	–
Incisional hernia	0.0%	0.6%[d]	–	–	–	0.1%[e]

[a] Not explicitly stated; 73% response rate at 3 years.
[b] Port/tubing: port displacement or infection, tubing disruption.
[c] Gastric: Necrosis, prolapse, erosion, gastro-esophageal perforation.
[d] All from conversion.
[e] Incarcerated.

a symptom free increase in weight due to loss of the band restriction. The patient may also report fever, pain, nausea, and vomiting due to port site infection. The inflammation at the site of infection can cause a weakening in the stomach wall, which may ultimately lead to erosion.

Unlike the diagnosis of slippage, band erosion cannot be detected by abdominal x-ray. Rather, endoscopy is needed to demonstrate the band in the gastric wall. The advantage of this modality is that it can also be therapeutic; if the band has asymptomatically migrated completely through the gastric wall and into the stomach, it can be endoscopically removed [37]. If the band erodes and causes symptomatic pain and bleeding, the band must be removed laparoscopically and the gastric wall sutured. In extreme cases inflammation of the tissues may necessitate a gastrectomy.

20.4.4 Port complications

The laparoscopic band procedure involves placement of a subcutaneous injection port that is attached to the tube connecting to the gastric band. A needle is used to inject saline into the port when necessary to adjust the inflation of the band. Difficulties with the port are another set of potential complications. Port malfunction causes an inability to adjust the band, as it is no longer possible to titrate the instilled volume of saline into the system. This complication is reported with an incidence of 0.4–7.0% [32, 38]. Patients usually present with weight gain since they can no longer maintain band volume from saline injection. Surgical repair is often required to replace the port or to better anchor the port if it has become dislodged. As ports are a foreign body, they can also become infected. This is seen in 0.3–9% of cases [39, 40] and requires surgical removal, especially if it occurs in association with band erosion.

20.4.5 Esophageal/pouch dilatation

With a band around the proximal stomach, dilatation of the proximal stomach and/or esophagus can develop. This is seen in up to 10% of patients [41]. Dilatation of the proximal portion of the stomach is more commonly seen in patients who have a history

of binge eating, possibly due to the more relaxed gastric wall [42]. As this dilatation becomes chronic and impairs the function of the lower esophageal sphincter, the dilation moves cephalad, resulting in esophageal dilatation. Esophageal dilatation, also known as "pseudoachalasia syndrome," can then result in significant esophageal reflux. Esophageal dilatation is commonly reversed by deflating the band, but persistent dilation may require conversion of LAGB to another bariatric procedure (commonly to RYGB) (Table 20.2).

20.5 Non-bariatric procedures

Obese patients sustain greater risks when undergoing any surgical procedures, due to both co-morbidities and anatomic factors. As previously mentioned, obese patients are at greater risk for development of a primary incisional hernia. They also have an increased incidence of hernia recurrence after repair [45]. Contributing factors include the technical challenges of closing the fascia in the face of significant amounts of surrounding fat, increased intra-abdominal pressure, and possibly impaired tissue healing and strength.

For patients undergoing open tracheostomy, obesity results in higher rates of late extratracheal placement, stoma infection, and tube obstruction [43]. Higher BMI is also a risk factor for lymphedema after axillary node dissection for breast cancer [44]. This may be partially due to delayed wound healing secondary to fat necrosis, which can lead to secondary infection and lymphangitis, causing lymphatic obstruction. Weight gain after breast surgery is also a risk factor for lymphedema progression. Obese patients may therefore require closer follow-up and a higher index of suspicion to detect long-term complications after surgery.

20.6 Summary

Obese patients pose unique challenges both from the perspective of peri-operative care and post-operative management. Bariatric surgery confers multiple benefits including weight loss, resolution of co-morbidities, and potentially improved quality of life. As for any surgery, these must be balanced with the surgical risks, which range from mortality to the need for medications or reoperation. From the standpoint of long-term mortality and morbidity, there has yet to be clear evidence of the best procedure for an individual patient, based on BMI or age. Decisions concerning the type of surgery and long-term management must be made on a unique patient by patient basis. Knowledge of the technical details as they relate to the potential complications of each bariatric procedure is critical for early diagnosis and treatment, allowing patients to benefit optimally from their weight loss.

References

1. Bucknall TE, Cox PJ, Ellis H. Burst abdomen and incisional hernia: a prospective study of 1129 major laparotomies. *Br Med J (Clin Res Ed)* 1982; **284**: 931–3.
2. Podnos YD, Jimenez JC, Wilson SE, Stevens CM, Nguyen NT. Complications after laparoscopic gastric bypass: a review of 3464 cases. *Arch Surg* 2003; **138**: 957–61.
3. Martikainen T, Pirinen E, Alhava E, Poikolainen E, Paakkonen M, Uusitupa M, *et al*. Long-term results, late complications and quality of life in a series of adjustable gastric banding. *Obes Surg* 2004; **14**: 648–54.
4. Balsiger BM, Poggio JL, Mai J, Kelly KA, Sarr MG. Ten and more years after vertical banded gastroplasty as primary operation for morbid obesity. *J Gastrointest Surg* 2000; **4**: 598–605.
5. Balsiger BM, Murr MM, Mai J, Sarr MG. Gastroesophageal reflux after intact vertical banded gastroplasty: correction by conversion to Roux-en-Y gastric bypass. *J Gastrointest Surg* 2000; **4**: 276–81.
6. Lopez PP, Patel NA, Koche LS. Outpatient complications encountered following Roux-en-Y gastric bypass. *Med Clin North Am* 2007; **91**: 471–83, xii.
7. Villegas L, Schneider B, Provost D, Chang C, Scott D, Sims T, *et al*. Is routine cholecystectomy required during laparoscopic gastric bypass? *Obes Surg* 2004; **14**: 206–11.
8. Wudel LJ, Jr., Wright JK, Debelak JP, Allos TM, Shyr Y, Chapman WC. Prevention of gallstone formation in morbidly obese patients undergoing rapid weight loss: results of a randomized controlled pilot study. *J Surg Res* 2002; **102**: 50–6.
9. Uy MC, Talingdan-Te MC, Espinosa WZ, Daez ML, Ong JP. Ursodeoxycholic acid in the prevention of gallstone formation after bariatric surgery: A meta-analysis. *Obes Surg* 2008; **18**: 1532–8.
10. Sugerman HJ, Brewer WH, Shiffman ML, *et al*. A multicenter, placebo-controlled, randomized, double-blind, prospective trial of prophylactic ursodiol for the prevention of gallstone formation following gastric-bypass-induced rapid weight loss. *Am J Surg* 1995; **169**: 91–6; discussion 6–7.
11. DeMaria EJ, Murr M, Byrne TK, *et al*. Validation of the obesity surgery mortality risk score in a multicenter study proves it stratifies mortality risk in patients undergoing gastric bypass for morbid obesity. *Ann Surg* 2007; **246**: 578–82; discussion 83–4.
12. Bult MJ, van Dalen T, Muller AF. Surgical treatment of obesity. *Eur J Endocrinol* 2008; **158**: 135–45.

13. Flum DR, Salem L, Elrod JA, Dellinger EP, Cheadle A, Chan L. Early mortality among Medicare beneficiaries undergoing bariatric surgical procedures. *JAMA* 2005; **294**: 1903–8.
14. Livingston EH, Huerta S, Arthur D, Lee S, De Shields S, Heber D. Male gender is a predictor of morbidity and age a predictor of mortality for patients undergoing gastric bypass surgery. *Ann Surg* 2002; **236**: 576–82.
15. Fernandez AZ Jr. Demaria EJ, Tichansky DS, *et al*. Multivariate analysis of risk factors for death following gastric bypass for treatment of morbid obesity. *Ann Surg* 2004; **239**: 698–702; discussion 702–3.
16. Buchwald H, Estok R, Fahrbach K, Banel D, Sledge I. Trends in mortality in bariatric surgery: a systematic review and meta-analysis. *Surgery*. 2007; **142**: 621–32; discussion 632–5.
17. Adams TD, Gress RE, Smith SC, *et al*. Long-term mortality after gastric bypass surgery. *N Engl J Med* 2007; **357**: 753–61.
18. Mizon C, Ruz M, Csendes A, Carrasco F, Rebolledo A, Codoceo J, *et al*. Persistent anemia after Roux-en-Y gastric bypass. *Nutrition* 2007; **23**: 277–80.
19. Service GJ, Thompson GB, Service FJ, Andrews JC, Collazo-Clavell ML, Lloyd RV. Hyperinsulinemic hypoglycemia with nesidioblastosis after gastric-bypass surgery. *N Engl J Med* 2005; **353**: 249–54.
20. Hedberg J, Hedenstrom H, Nilsson S, Sundbom M, Gustavsson S. Role of gastric acid in stomal ulcer after gastric bypass. *Obes Surg* 2005; **15**: 1375–8.
21. Gumbs AA, Duffy AJ, Bell RL. Incidence and management of marginal ulceration after laparoscopic Roux-Y gastric bypass. *Surg Obes Relat Dis* 2006; **2**: 460–3.
22. Schirmer B, Erenoglu C, Miller A. Flexible endoscopy in the management of patients undergoing Roux-en-Y gastric bypass. *Obes Surg* 2002; **12**: 634–8.
23. Filho AJ, Kondo W, Nassif LS, Garcia MJ, Tirapelle Rde A, Dotti CM. Gastrogastric fistula: a possible complication of Roux-en-Y gastric bypass. *JSLS* 2006; **10**: 326–31.
24. Blachar A, Federle MP, Pealer KM, Ikramuddin S, Schauer PR. Gastrointestinal complications of laparoscopic Roux-en-Y gastric bypass surgery: clinical and imaging findings. *Radiology* 2002; **223**: 625–32.
25. Sandrasegaran K, Rajesh A, Lall C, Gomez GA, Lappas JC, Maglinte DD. Gastrointestinal complications of bariatric Roux-en-Y gastric bypass surgery. *Eur Radiol* 2005; **15**: 254–62.
26. Papasavas PK, Caushaj PF, McCormick JT, Quinlin RF, Hayetian FD, Maurer J, *et al*. Laparoscopic management of complications following laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Surg Endosc* 2003; **17**: 610–4.
27. Cho M, Carrodeguas L, Pinto D, *et al*. Diagnosis and management of partial small bowel obstruction after laparoscopic antecolic antegastric Roux-en-Y gastric bypass for morbid obesity. *J Am Coll Surg* 2006; **202**: 262–8.
28. Goitein D, Papasavas PK, Gagne D, Ahmad S, Caushaj PF. Gastrojejunal strictures following laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Surg Endosc* 2005; **19**: 628–32.
29. Jones KB. Biliopancreatic limb obstruction in gastric bypass at or proximal to the jejunojejunostomy: A potentially deadly, catastrophic event. *Obes Surg* 1996; **6**: 485–93.
30. FDA Trial Summary of Safety and Effectiveness Data: The Lap-Band Adjustable Gastric Banding System (P000008). Available at www.fda.gov/.
31. Martin LF, Smits GJ, Greenstein RJ. Treating morbid obesity with laparoscopic adjustable gastric banding. *Am J Surg* 2007; **194**: 333–43; discussion 44–8.
32. Ren CJ, Horgan S, Ponce J. US experience with the LAP-BAND system. *Am J Surg* 2002; **184**: 46S–50S.
33. Ren CJ, Fielding GA. Laparoscopic adjustable gastric banding: surgical technique. *J Laparoendosc Adv Surg Tech A* 2003; **13**: 257–63.
34. Dargent J. Surgical treatment of morbid obesity by adjustable gastric band: the case for a conservative strategy in the case of failure – a 9-year series. *Obes Surg* 2004; **14**: 986–90.
35. Pasnik K, Krupa J, Stanowski E. Vertical banded gastroplasty: 6 years experience at a center in Poland. *Obes Surg* 2005; **15**: 223–7.
36. Meir E, Van Baden M. Adjustable silicone gastric banding and band erosion: personal experience and hypotheses. *Obes Surg* 1999; **9**: 191–3.
37. Regusci L, Groebli Y, Meyer JL, Walder J, Margalith D, Schneider R. Gastroscopic removal of an adjustable gastric band after partial intragastric migration. *Obes Surg* 2003; **13**: 281–4.
38. Dargent J. Laparoscopic adjustable gastric banding: lessons from the first 500 patients in a single institution. *Obes Surg* 1999; **9**: 446–52.
39. Angrisani L, Furbetta F, Doldi SB, *et al*. Lap Band adjustable gastric banding system: the Italian experience with 1863 patients operated on 6 years. *Surg Endosc* 2003; **17**: 409–12.
40. Cadiere GB, Himpens J, Hainaux B, Gaudissart Q, Favretti S, Segato G. Laparoscopic adjustable gastric banding. *Semin Laparosc Surg* 2002; **9**: 105–14.
41. DeMaria EJ, Sugerman HJ, Meador JG, Doty JM, Kellum JM, Wolfe L, *et al*. High failure rate after laparoscopic adjustable silicone gastric banding for treatment of morbid obesity. *Ann Surg* 2001; **233**: 809–18.
42. Poole N, Al Atar A, Bidlake L, *et al*. Pouch dilatation following laparoscopic adjustable gastric banding: psychobehavioral factors (can psychiatrists predict pouch dilatation?). *Obes Surg* 2004; **14**: 798–801.

43. El Solh AA, Jaafar W. A comparative study of the complications of surgical tracheostomy in morbidly obese critically ill patients. *Crit Care* 2007; **11**: R3.
44. Mak SS, Yeo W, Lee YM, *et al*. Predictors of lymphedema in patients with breast cancer undergoing axillary lymph node dissection in Hong Kong. *Nurs Res* 2008; **57**: 416–25.
45. Sauerland S, Korenkov M, Kleinen T, Arndt M, Paul A. Obesity is a risk factor for recurrence after incisional hernia repair. *Hernia* 2004; **8**: 42–6.
46. MacLean LD, Rhode BM, Nohr CW. Late outcome of isolated gastric bypass. *Ann Surg* 2000; **231**: 524–8.
47. White S, Brooks E, Jurikova L, Stubbs RS. Long-term outcomes after gastric bypass. *Obes Surg* 2005; **15**: 155–63.
48. Capella RF, Iannace VA, Capella JF. Reducing the incidence of incisional hernias following open gastric bypass surgery. *Obes Surg* 2007; **17**: 438–44.
49. Schauer PR, Ikramuddin S, Gourash W, Ramanathan R, Luketich J. Outcomes after laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Ann Surg* 2000; **232**: 515–29.
50. Higa KD, Ho T, Boone KB. Laparoscopic Roux-en-Y gastric bypass: technique and 3-year follow-up. *J Laparoendosc Adv Surg Tech A* 2001; **11**: 377–82.
51. Suter M, Paroz A, Calmes JM, Giusti V. European experience with laparoscopic Roux-en-Y gastric bypass in 466 obese patients. *Br J Surg* 2006; **93**: 726–32.
52. Belachew M, Belva PH, Desaive C. Long-term results of laparoscopic adjustable gastric banding for the treatment of morbid obesity. *Obes Surg* 2002; **12**: 564–8.
53. Zinzindohoue F, Chevallier JM, Douard R, *et al*. Laparoscopic gastric banding: a minimally invasive surgical treatment for morbid obesity: prospective study of 500 consecutive patients. *Ann Surg* 2003; **237**: 1–9.
54. Mittermair RP, Weiss H, Nehoda H, Kirchmayr W, Aigner F. Laparoscopic Swedish adjustable gastric banding: 6-year follow-up and comparison to other laparoscopic bariatric procedures. *Obes Surg* 2003; **13**: 412–7.
55. Weiner R, Blanco-Engert R, Weiner S, Matkowitz R, Schaefer L, Pomhoff I. Outcome after laparoscopic adjustable gastric banding – 8 years experience. *Obes Surg* 2003; **13**: 427–34.
56. Parikh MS, Fielding GA, Ren CJ . US experience with 749 laparoscopic adjustable gastric bands: intermediate outcomes. *Surg Endosc* 2005; **19**: 1631–5.

Chapter 21

Anesthetic considerations for the post-bariatric surgery patient

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21.1 Introduction

The prevalence of obesity in the US has doubled since 1980. More than one third of the adult population, an estimated 72 million people, are now classified as obese (body mass index (BMI) > 30 kg m^{-2})[1]. Obesity is a known risk factor for diabetes, cardiovascular disease, hypertension, certain cancers, obstructive sleep apnea, and is associated with increased disability and a modestly elevated risk of all-cause mortality [1, 2]. The Swedish Obese Subjects (SOS) study demonstrated health advantages with long-term weight reduction following bariatric surgery in MO patients [3] (Figure 21.1). The number of patients electing bariatric surgery as either a primary means of weight reduction or a means of last resort is anticipated to rise. An estimated 205 000 people in the USA underwent bariatric surgery in 2007 [4] (Figure 21.2). Anesthesiologists, surgeons, and other peri-operative caregivers should anticipate that patients who have had previous bariatric surgery will present for other operative procedures with increasing frequency in the future. Post-bariatric surgical patients have unique, altered physiology, and those managing these patients must be aware of potential complications. To date there is little research in this area. This chapter will review the the care of the post-bariatric surgical patient and explore the theoretic concerns presented in this patient population.

21.2 Nutritional deficiencies following bariatric surgery

Bariatric operations can be divided into two major categories [5]. The first includes restrictive procedures of the stomach, such as laparoscopic adjustable gastric banding, gastric stapling, and vertical banded gastroplasty (Figure 21.3). The second category consists of procedures designed to intentionally create a malabsorptive state, usually combined with a restrictive procedure. The most popular combination procedure is the Roux-en-Y gastric bypass (RYGB). Another procedure in this category is biliopancreatic diversion (BPD), which combines minor gastric restriction with significant intestinal bypass resulting in a highly malabsorptive procedure. Duodenal switch (DS) is another highly malabsorptive combination procedure in which the gastric restriction maintains the distal stomach and pylorus, and is usually reserved for the super obese (BMI > 50 kg m^{-2}). Jejunoileal bypass is a pure malabsorptive procedure that is no longer performed secondary to a very high incidence of complications, which included hepatic failure with cirrhosis, autoimmune disorders, and profound nutritional deficiencies [5, 6].

When compared to restrictive procedures, malabsorptive procedures have a higher incidence of nutritional deficiencies and complications, which can present the anesthesiologist with challenges during the peri-operative period [7]. To help prevent these various deficiencies, management of post-bariatric patients should entail routine follow up in a nutritional clinic where supplements can be optimized. Unfortunately, nutritional deficiencies can still exist despite attendance at these clinics and adherence to their recommendations [9]. In the malnutrition state after bariatric surgery multiple nutritional deficiencies can coexist.

Iron deficiency is present in up to one third of post-bariatric patients and is due to multiple factors. For absorption, ferric iron present in food must be reduced to the ferrous state by hydrochloric acid. The ferrous form is mainly absorbed in the duodenum and jejunum [7, 8].

After bypass surgeries, there is reduced gastric acid production due to bypassed gastric tissue, and there is less small bowel present to absorb nutrients. The latter

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

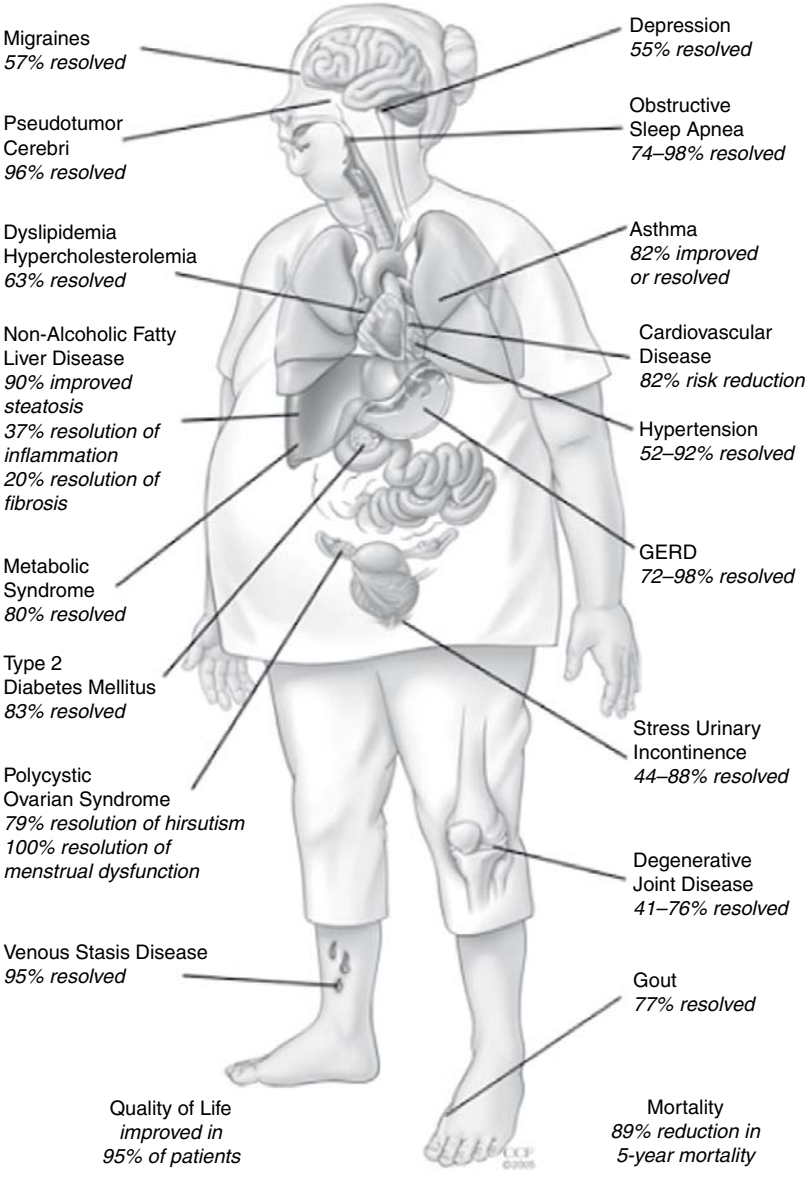

Figure 21.1 Health advantages of long-term weight loss. From http://gastricbypasstruth.com/2008/06/gastric-bypass-benefits-other-than-weight-loss. (Accessed 11/14/2008; From Cleveland clinic 2007.)

may be potentiated by concomitant administration of H_2 blockers and proton pump inhibitors, although such medications are not routinely necessary after RYGB [9]. Iron deficiency is most commonly symptomatic in menstruating women. The resultant microcytic anemia yields erythrocytes that display reduced deformability, which may play a role in decreased cellular lifespan as well as decreased rheology in the microcirculation [10].

Protein deficiencies may develop due to decreased intake secondary to intolerance of protein containing foods and beverages [7]. This intolerance typically can last up to 1 year post-bariatric surgery, although hypo-albuminemia has been reported in up to 13% of patients 2 years following surgery. The nadir for albumin levels is at 1–2 years and corresponds with transition from a rapid weight loss phase to a slower weight loss phase [9]. Low levels of serum proteins may influence the free fractions of highly protein-bound drugs [11,12]. Information on the amount of protein binding for common anesthetic drugs is included in Table 21.1. In general, albumin tends to bind acidic compounds such as etomidate while alpha-1-acid glycoprotein binds basic drugs like amide local anesthetics. Alpha-1-acid glycoprotein is also an acute phase reactant

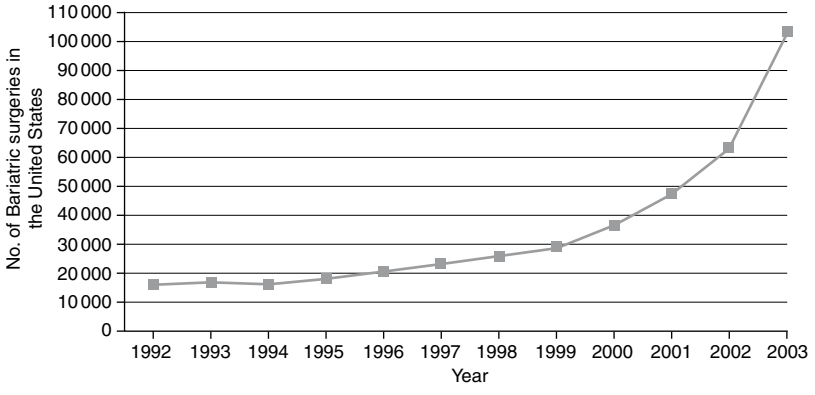

Figure 21.2 Estimated number of bariatric operations performed in the United States, 1992–2003. From Steinbrook R. Surgery for severe obesity. *N Engl J Med* 2004; **350**: 1075–9.

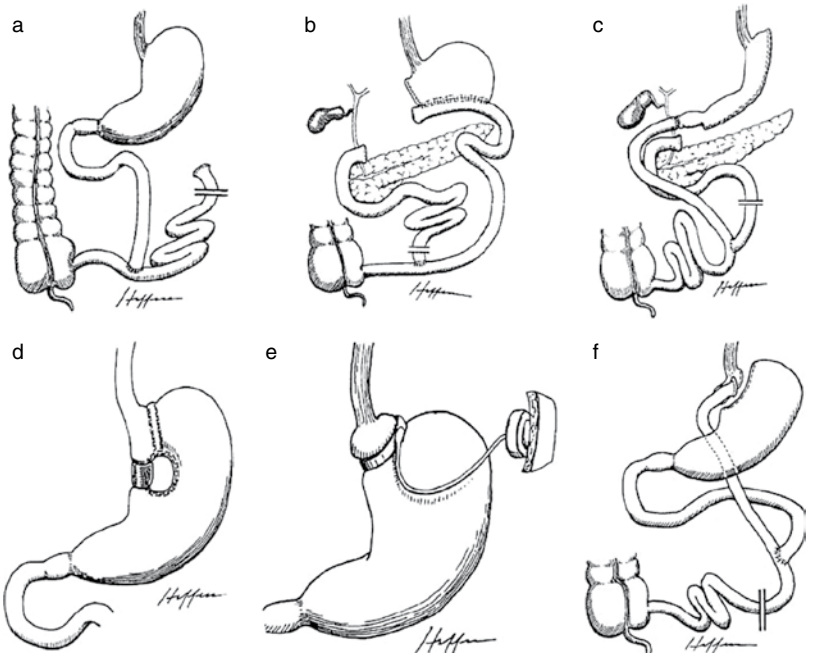

Figure 21.3 Types of bariatric procedures. (a) jejunoileal bypass; (b) biliopancreatic diversion; (c) biliopancreatic diversion with duodenal switch; (d) vertical banded gastroplasty; (e) laparoscopic adjustable gastric band; and (f) Roux-en-Y gastric bypass. From Mun et al. Current status of medical and surgical therapy for obesity. *Gastroenterology* 2001; **120**: 669–681.

that increases in concentration during inflammatory phases, as can occur during the post-operative period [13]. Careful titration of medication administration can help prevent adverse side effects.

Calcium is preferentially absorbed in the duodenum and proximal jejunum, while vitamin D is preferentially absorbed in the jejunum and ileum [7]. Obesity can predispose patients to low bone mass, as 60% of obese patients have low levels of vitamin D, and 25–48% have increased parathyroid hormone levels [14]. Combining this pre-operative state with malabsorptive surgery, subsequent reduced oral intake and rapid weight loss places post-bariatric patients at high risk for metabolic bone disease. Post-menopausal women and hypogonadal men have an even greater risk [9]. Metabolic bone disease increases fracture risk and can manifest clinically as a complaint of skeletal "aches and pains."

In addition to vitamin D, other fat soluble vitamin deficiencies can develop after bariatric surgery including vitamins A (5–69% of patients), K (50%) and E (5%) [9]. The greatest deficiencies occur following DS and BPD procedures due to greater degree of malabsorption with these operations (Figure 21.3). Ten percent of patients had a vitamin A deficiency 4 years after RYGB despite taking multivitamins [7]. Vitamin A deficiency can result in visual disturbances at night, although these complaints are rare. It is unknown if patients with vitamin A deficiency are at higher peri-operative risk of visual complications. Should a patient present

Table 21.1 Protein binding of commonly used anesthetic agents

Drug	Percent protein bound	Predominant protein type	PKa
Propofol	97–99%		11.03
Etomidate	76.5%	Albumin	4.24
Thiopental Sodium	60.4–96.7%		7.6
Ketamine	47%		7.5
Rocuronium	30%		
Vecuronium	60–80%		
Fentanyl	80–86%	Albumin, AAG, erythrocytes	
Sufentanil	93%	Largely AAG	
Hydromorphone	20%		
Morphine	20–36%		
Meperidine	65–80%	AAG & Albumin	
Metoprolol	12%		
Labetalol	50%		
Atropine	4.9–23.1%		
Ondansetron	70–76%		
Promethazine	93%		9.1
Lidocaine	33–80%	AAG	7.8
Bupivacaine	95%	AAG & albumin	8.1
Ropivacaine	94%	AAG	8.1
Mepivacaine	75%		7.6

AAG, alpha-1-acid glycoprotein. In vitro, meperidine binding was independent of albumin concentration but was dependent upon AAG concentration. Free bupivicaine levels are higher in parturients likely secondary to decreased concentrations of AAG. Amide local anesthetics have 5000 times higher affinity for AAG than albumin.
Source: Fryer, M. Intravenous induction agents *Anaesthes Intensive Care Med* 2004; **5**: 317–21.

with this condition, it is reasonable to exercise caution in maneuvers and operations which increase intraocular pressure, such as prone positioning and prolonged Trendelenburg position.

Vitamin K deficiency has been noted in more than half of post-bariatric patients, although no bleeding diatheses have been reported in these patients. Multiple case reports do exist linking vitamin K deficiency with intracranial hemorrhage [15]. One study of malnourished cancer patients reported elevated INR levels > 1.5 with low vitamin K levels in 6.5% of patients [16], and a case report linked vitamin K deficiency with a thoracic epidural hematoma in a 72- year-old man after total gastrectomy [17]. If considering a regional anesthetic in post-bariatric surgical patients, it is advisable to evaluate the patient's coagulation status given the prevalence of vitamin K deficiency and the potential catastrophic complication of a hematoma.

Acquired vitamin E deficiency takes decades to develop and presents with neurologic problems involving a spino-cerebellar syndrome with variable peripheral nerve involvement [18]. This condition presents clinically with ataxia, hyporeflexia, loss of proprioception, and loss of vibratory sensation. Many nutritional deficiencies can adversely affect neurologic function. As will be discussed in the management section, all neurologic deficits should be noted pre-operatively, and extra efforts should be taken during positioning to minimize the likelihood of exacerbating present and latent neuropathies. Additionally, documentation of pre-existing neurologic deficits is always recommended prior to performing a regional anesthetic.

The last noteworthy fat-soluble vitamin is zinc and deficiencies have been noted in 10–50% of patients after bariatric surgery. Zinc deficiency usually manifests as alopecia [7].

Bariatric surgery also causes deficiencies in water-soluble vitamins. This is largely influenced by the decrease in acid production caused by loss of parietal

cells in the bypassed stomach. Vitamin B_1, or thiamine, requires an acidic environment for absorption in the proximal intestine [7]. Thiamine deficiency is present in <0.2% of post-bariatric patients [19]. Thiamine functions as a coenzyme in the metabolism of carbohydrates and branched-chain amino acids and has a role in metabolic and nerve functions, particularly acetylcholine receptor clustering and acetylcholine synthesis [6, 18]. The minimal stores of thiamine in the body can be depleted within 2–3 weeks in a dietary deficient state [7]. Deficiency can manifest as beriberi (which can present as high output cardiac failure) or Wernicke's encephalopathy (WE).

Wernicke's encephalopathy usually occurs 2–5 months after bariatric surgery and is associated with persistent or profound vomiting. Classically, WE presents as a triad of mental confusion, ophthalmoplegia (nystagmus), and gait ataxia, although all components of the triad may not be present [20, 21]. It can also present with other clinical findings such as vestibular dysfunction without hearing loss, peripheral neuropathy (typically of lower extremities), hypothermia, and cardiovascular abnormalities [21]. The latter includes tachycardia, exertional dyspnea, electrocardiogram abnormalities, and elevated cardiac output. Wernicke's encephalopathy can be precipitated by the administration of glucose prior to thiamine supplementation. If untreated WE can result in a chronic condition known as Korsakoff's syndrome [21]. If thiamine deficiency is suspected, treatment takes priority over diagnosis. Response to therapy can be diagnostic.

The traditional dosing regimen consists of parenteral thiamine, 100 mg IV followed by 100 mg IM/IV q24 hours for 5 days. No randomized controlled study has been performed to determine optimal dosages. This approach is considered safe, inexpensive, and effective; however, rare anaphylactic events have been reported [21, 22]. If one has a high suspicion of WE, and the above regimen is ineffective in treating the mental status changes and ocular palsy, a dose up to 500 mg thiamine IV should be given and may need to be repeated 2–3 times per day [22]. Ocular manifestations are typically the first to resolve (hours to days) followed by resolution of confusion (days to weeks) [21].

Vitamin B_{12} (cobalamin) is another water-soluble vitamin that is deficient in 12–70% of post-bariatric patients [6]. B_{12} is essential for DNA synthesis and has a role in neuronal function. Similar to other nutrients, an acidic environment is necessary to separate B_{12} from protein in food. Compounding this is the lack of intrinsic factor secretion from parietal cells of the bypassed stomach. Deficiency typically takes years to manifest as the body has 2–5 mg of B_{12} stored, while the daily requirements are 6–9 mcg per day [23].

B_{12} deficiency classically produces a megaloblastic-macrocytic anemia and hypersegmented neutrophils. However, many B_{12} deficient patients present with no anemia and the macrocytosis may be masked by a coexistent iron deficiency [24]. B_{12} deficiency is associated with peripheral neuropathy and subacute combined degeneration of the spinal cord. Neurologic symptoms can be present even if anemia or macrocytosis is not [25]. The subacute combined degeneration manifests as white matter lesions in the posterior column and pyramidal tract with highest severity in the cervical and upper thoracic regions, and can progress from demyelination to axonal degeneration and neuronal death [18, 26]. This presents clinically as limb weakness, difficulty with proprioception, and loss of fine motor skills. If untreated, symptoms can progress to spasticity, incontinence, and paraplegia [23, 26]. Neuropsychiatric manifestations include decreased memory, personality change, psychosis, and, rarely, delirium [18]. Treatment with B_{12} can halt progression, but only leads to complete resolution of symptoms in a small percentage of patients that have less severe disease [27].

Patients that are B_{12} deficient can develop neurologic dysfunction after anesthesia involving prolonged administration of nitrous oxide [28]. This may be preventable by avoiding nitrous oxide in post-bariatric surgical patients or by administering prophylactic B_{12} in the weeks before surgery [18].

Folic acid deficiency has a clinical presentation similar to B_{12} deficiency presenting with megaloblastic anemia. Body stores of folate are minimal (5–10 mg) and symptoms can manifest after 4–5 months of a folate deficient diet [23]. Neurologic deficits associated with folate deficiency are rare and usually mild [18]. However, reports have linked subacute combined degeneration of the spinal cord to folate deficiency after ruling out B_{12} and other nutrient deficiencies [29].

Copper is a trace element whose deficiency has been linked to a myeloneuropathy similar to subacute combined degeneration of the spinal cord [20]. Additionally, neurologic deficits can be present without the associated anemia and leucopenia of copper deficiency [18].

21.3 Complications of bariatric surgery

Complications associated with bariatric procedures can be subdivided into three phases based on chronology: (a) peri-operative, (b) short term (within the first year), and (c) long term [30].

Peri-operative complications include post-operative anastomotic leaks, intra-abdominal and gastrointestinal hemorrhage, bowel perforation, bowel obstruction, wound infection, pneumonia, myocardial infarction, deep venous thrombosis, and pulmonary embolism [31–33]. Many of these early complications are treated by repeat surgeries, however, since they occur shortly after the bariatric procedure very little weight loss or nutritional deficiency will be present at this time. Anesthetic management will be similar to that for the MO patient, compounded by whatever surgical complication is being treated (see Chapters 16 and 20).

Short-term complications occur during the first year post-operation are usually related to weight loss. They commonly include chronic nausea, vomiting, dumping syndrome, gallstones, diarrhea, dehydration, food intolerance, and anastomotic ulcers [6]. Short-term complications cause the patient to learn new eating habits and to become skilled at interpreting their own physiologic feedback [30]. Additionally, psychologic problems may become manifest as the patient deals with the psychosocial challenges associated with their new thinner body habitus [30].

Vomiting occurs in < 10% of patients following malabsorptive procedures, but is common and can occur weekly in 50% of patients following restrictive procedures [9]. It is usually secondary to ill-advised eating habits, but can rarely be secondary to mechanical obstruction such as anastomotic stenosis or over-tightening of the gastric band. As mentioned previously, prolonged vomiting can be associated with neurologic deficits such as Wernicke's encephalopathy. The implications for the anesthesiologist of frequent vomiting include the need to be aware of patient volume status, the potential for metabolic alkalosis, the possibility of multiple nutritional derangements, as well as a consideration for rapid sequence anesthetic induction with rapid airway control.

Dumping syndrome is a malabsorptive procedure complication and occurs most frequently in the first several months after RYGB [6]. This process typically begins with a high sugar diet and has two phases, both of which are associated with gastrointestinal and/or autonomic symptoms. The gastrointestinal symptoms include nausea and vomiting, cramps, and diarrhea. The autonomic symptoms include tremulousness, sweating, flushing, lightheadedness, and syncope. The early phase is due to rapid transit of hyperosmolar food causing fluid shifts and is compounded by enteropeptide secretion. The late phase occurs 1–3 hours later and is caused by hyperinsulinemic hypoglycemia [6]. Since all surgical patients are asked to fast pre-operatively, dumping syndrome should not occur intra-operatively. However, careful history taking with assessment of volume deficits from pre-operative vomiting or diarrhea can help guide intra-operative fluid management.

Table 21.2 Factors associated with increased risk of neuropathy

Rapid weight loss
Prolonged gastrointestinal symptoms (vomiting, dumping syndrome, diarrhea)
Not attending a nutritional clinic
Malnutrition state (reduced albumin and transferrin post-operatively)
Having post-operative surgical complications
History of jejunoileal bypass

Late complications include bowel obstruction, gallstones, anastomotic stricture, incisional hernia, marginal ulceration, band erosion or slippage, steatorrhea, and the aforementioned nutritional deficiencies [9]. Steatorrhea can be indicative of fat-soluble vitamin deficiency, and patients usually complain of malodorous gas or stool.

Neurologic complications may be present in 5–16% of patients who have had bariatric surgery, and can occur in any post-operative time period [18]. Peripheral neuropathy is the most commonly reported neurologic complication and is associated with multiple risk factors [6] (Table 21.2). The most common mono-neuropathy is the median nerve (carpal tunnel syndrome) followed by the radial, ulnar, lateral femoral cutaneous (meralgia paresthetica), peroneal, sciatic, and the greater occipital nerves [6]. The exact mechanism for these neuropathies is unknown but may be secondary to nutritional deficiencies combined with a physical insult. For example, it is possible that peroneal neuropathy results from the loss of a fat pad protecting the nerves from compression and that rapid weight loss leaves the median nerve more susceptible to compression [6, 34]. Other patients have anatomic variation in the course of their lateral femoral cutaneous nerve that can leave them more susceptible to compression from pannicular traction on the inguinal ligament [35].

The anesthetic implications of these neuropathies are unknown, however, when planning a regional anesthetic or continuous catheter for post-operative pain control, documentation of any neurologic deficit that is present is prudent.

Acute post-gastric reduction surgery (APGARS) neuropathy is a rare complication. This is a complex of protracted vomiting, hyporeflexia, and muscle weakness. Surprisingly, less than half of the patients diagnosed with APGARS were found to have a vitamin deficiency [19]. In this study, 18 of the 40 patients that had a vitamin deficiency had resolution after treatment with thiamine or B_{12}. Unfortunately this study only looked at B_1 and B_{12} deficiency and did not consider other nutritional deficiencies as possible contributors to the development of APGARS. The anesthetic implications of APGARS are unknown. Similar to other patients with protracted vomiting, volume and acid/base status should be addressed. If the patient is experiencing muscle weakness preoperatively, the potential for post-operative ventilation should be discussed. No matter what, since the effects of neuromuscular blockade in a patient with APGARS is unknown, careful titration with a neuromuscular monitor should be used to guide administration.

Another very rare condition that is becoming more recogonized after bariatric surgery is autonomic dysfunction. Profound orthostatic hypotension occuring approximately 8 months after surgery has been reported in two patients [36, 37]. Both patients had normal volume status and cardiac function. These patients had a history of hypertension and diabetes with accompanying neuropathy. Presumably, prior to bariatric surgery increased blood pressure masked the presence of autonomic dysfunction caused by the diabetes. Following weight loss the hypertension resolved, exposing the autonomic dysfunction. The anesthetic implications of autonomic dysfunction include poor vasoconstriction, decreased extracellular fluid, supine hypertension, and heat-induced hypotension [38]. This condition requires invasive blood pressure monitoring, and use of vasopressors and vasodilating agents during subsequent anesthetics.

Psychologic problems are present in the MO population with 40% of patients receiving psychiatric treatment [39]. Body image dissatisfaction is pervasive in these patients and is associated with symptoms of depression and decreased self-esteem [39]. A higher incidence of psychopathology was found in patients with a history of binge eating disorder, defined as the *uncontrollable* eating of large amounts of food in 2 hours [40]. Despite this, the great majority of patients after bariatric surgery note an improvement in psychosocial function by 12–18 months post-operatively [9]. However, some patients can display major post-operative psychiatric distress from unrecognized pre-surgical mood disorder conditions such as bipolar or post-traumatic stress disorder. Two small studies reported that as many as a third of bariatric patients have a history of childhood sexual abuse [9]. The anesthesiologist should be caring and understanding and aware of the increased likelihood of psychopathology and should tailor the anesthetic plan accordingly.

21.4 Assessment and management

The pre-operative assessment of the post-bariatric surgical patient should begin with a focus on airway and cardiopulmonary status. Significant weight reduction should lead to an improvement in airway anatomy due to a reduction in oropharyngeal fat, reduced neck girth, and greater neck range of motion. A meta-analysis reported that 84% of patients with obstructive sleep apnea experienced resolution or improvement of their symptoms following bariatric surgery [41]. Cardiopulmonary status may also improve in the post-bariatric patient [42]. However, if the patient prior to bariatric surgery had obesity hypoventilation syndrome or Pickwickian syndrome, it is possible that RV damage, pulmonary hypertension, hypoxemia with secondary polycythemia may still exist. If so, an extensive work-up may be necessary since it can impact the management of that patient. The proper selection of pre-operative testing should be guided by the history and physical combined with the risk level of the surgical procedure [43]. Appropriate questions specific to this population are included in Table 21.3. Affirmative answers may suggest nutritional deficits and might be predictive of post-operative complications such as neuropathy or delirium.

The physical exam should be guided by current health status, co-morbidities, and positive history findings. A thorough neurologic exam is advised, especially if a nutritional deficiency is suspected or if the patient displays risk factors for developing a neuropathy (Table 21.2).

The surgical literature has contradictory reports concerning improvement in gastroesophageal reflux disease (GERD) after restrictive procedures (e.g., laparascopic gastric banding and vertical banded gastroplasty) [45]. Some report resolution of symptoms while others report worsening of gastric reflux or new onset of reflux after the restrictive procedure. Pre-operative administration of H_2 blockers, prokinetic agents, and non-particulate antacids should be considered in patients who have had restrictive bariatric

Table 21.3 Pertinent history for the post-bariatric patient that can help to identify patients more prone to peri-operative complications

Type of bariatric surgery performed, associated surgical complications or prolonged hospital stay
Amount of weight loss since surgery, rate of current weight loss vs. weight maintenance
Current functional status and relate to presurgical state. Rule out active cardiac lesions and assess cardiac clinical risk factors
Lightheadedness upon standing
History of obstructive sleep apnea and improvement
Any new neurologic deficits: numbness/tingling in extremities, weakness, loss of proprioception, incontinence, visual changes such as difficulty seeing at night (Vit A deficiency vs. cataract), difficulty with concentration, change in mood
Examine medication list for psychiatric medications, ask compliance with regimen
Attendance at nutrition clinic and taking appropriate vitamin supplements
Significant GI symptoms: emesis, dumping syndrome, diarrhea, foul smelling gas/stool
Assess risk of anemia due to GI bleed, menstruation, or deficiencies of iron, B_{12}, or folate
Assess risk of bleeding secondary to medications, non-alcoholic fatty liver disease, vitamin K deficiency, thrombocytopenia
Cessation of menses should not be assumed secondary to rapid weight loss and pregnancy testing should be arranged

procedures. Conversely, patients that have had RYGB typically have resolution of GERD, making prophylactic therapy unnecessary [45].

A history of restrictive surgery should alter anesthetic induction plans due to the possible higher risk of pulmonary aspiration [46, 47]. This increased risk is secondary to decreased lower esophageal sphincter tone and abnormal esophageal peristalsis. To decrease the chances of aspiration pneumonitis, patients should be advised to consume a liquid diet (soups, stewed fruit, etc.) the day prior to surgery [46]. Additionally, a rapid sequence anesthetic induction with tracheal intubation should be performed.

Special attention is required during patient positioning to protect vulnerable areas so as not to exacerbate any present or latent neuropathies. Intra-operative use of nitrous oxide should be avoided due to possibility of subacute combined degeneration of the spinal cord and other complications associated with B_{12} and folate deficiencies. Additionally, caution should be used in administering glucose without thiamine supplementation due to the potential of WE.

If delirium is encountered post-operatively, one should first consider – in the following order – hypoxia, hypoglycemia, and history of psychopathology. If these are normal, then WE should be considered, along with the administration of thiamine, as described earlier. Post-operative physical exam should also be performed to detect the presence of other neurological deficits. If nitrous oxide was used intra-operatively, a B_{12} and folate deficiency should be strongly considered. If therapy is urgently required, baseline laboratory values for serum cobalamin (vitamin B_{12}) and serum folate should be obtained prior to therapy. Therapy should include both folate and B_{12} until the laboratory results return [24]. Parenteral vitamin B_{12} should be given 1000 mcg IM q24 h for 7 days followed by 1000 mcg a week for 4 weeks. Monthly 1000 mcg injections may be necessary. This therapy is safe, inexpensive, and excess vitamin B_{12} will simply be excreted in the urine [24]. Folate should be given 1 mg every 24 h orally and is effective even in malabsorption [24]. Parenteral dosing is 1 mg SC/IM and may be the desired route post-operatively. Copper deficiency may also produce similar neurologic deficits, and should be considered if levels of the previous nutrients return as normal. If neurologic deficits arise, a neurologic consult may be necessary to help guide management after discharge from the post-anesthesia care unit.

21.5 Conclusion

Increasing numbers of patients who have previously had bariatric surgery will require anesthetic management for subsequent surgical procedures. These patients, following weight loss, will have a reduction in cardiac risk factors when compared to a matched but non-operated cohort [3]. However, altered physiology in the post-bariatric surgical patient with malabsorption requires an understanding of the potential complications associated with numerous nutritional deficiencies. Knowledge of potential complications allows therapeutic interventions that enhance the likelihood of successful outcomes.

References

1. Ogden CL, Carroll MD, McDowell MA, *et al*. Obesity Among Adults in the United States – No statistically Significant Change Since 2003–2004. 2007. http://www.cdc.gov/nchs/data/databriefs/db01.pdf (Accessed 11/12/2008).
2. Bessesen D. Update on Obesity. *J Clin Endocrinol Metab* 2008; **93**: 2027–34.
3. Sjöström L, Lindroos AK, Peltonen M, *et al*. Lifestyle, diabetes, and cardiovascular risk factors 10 years after bariatric surgery. *N Engl J Med* 2004; **351**: 2683–93.

4. American Society for Metabolic and Bariatric Surgery. Fact Sheet: Metabolic and Bariatric Surgery. 2008. http://www.asbs.org/Newsite07/media/fact-sheet1_bariatric-surgery.pdf (Accessed 11/12/2008).
5. Decker GA, Swain JM, Crowell MD, Scolapio JS. Gastrointestinal and nutritional complications after bariatric surgery. *Am J Gastroenterol* 2007; **102**: 2571–80.
6. Thaisetthawatkul P. Neuromuscular complications of bariatric surgery. *Phys Med Rehabil Clin N Am* 2008; **19**: 111–24.
7. Davies DJ, Baxter JM, Baxter JN. Nutritional deficiencies after bariatric surgery. *Obesity Surgery* 2007; **17**: 1150–8.
8. Decker GA, Swain JM, Crowell MD, *et al*. Gastrointestinal and nutritional complications after bariatric surgery. *Am J Gastroenterol* 2007; **102**: 2571–80.
9. McMahon MM, Sarr MG, *et al*. Clinical management after bariatric surgery: Value of a multidisciplinary approach. *Mayo Clin Proc* 2006; **81** (10, supp i): S34-S45.
10. Vayá A, Simó M, Santaolaria M, *et al*. Red blood cell deformability in iron deficiency anemia. *Clin Hemorheol Microcirc* 2005; **33**: 75–80.
11. Bailey DN, Briggs JR. The binding of selected therapeutic drugs to human serum alpha-1 acid glycoprotein and to human serum albumin in vitro. *Ther Drug Monit* 2004; **26**: 40–3.
12. Dasgupta A. Usefulness of monitoring free (unbound) concentrations of therapeutics drugs in patient management. *Clinica Chimica Acta* 2007; **377**: 1–13.
13. Booker PD, Tayloc C, Saba G. Perioperative changes in alpha-1-acid glycoprotein concentrations in infants undergoing major surgery. *Br J Anaesth* 2007; **76**: 365–8.
14. Williams SE, Cooper K, Richmond B, *et al*. Perioperative management of bariatric surgery patients: Focus on metabolic bone disease. *Cleveland Clinic J Med* 2008; **75**: 333–49.
15. Van Mieghem T, Van Schoubroeck D. Fetal cerebral hemorrhage caused by vitamin K deficiency after complicated bariatric surgery. *Obstet Gynecol* 2008; **112**: 434–6.
16. Harrington DJ, Western H, *et al*. A study of the prevalence of vitamin K deficiency in patients with cancer referred to a hospital palliative care team and its association with abnormal haemostasis. *J Clin Pathol* 2008; **61**: 537–40.
17. Hirata N, Kanaya N, *et al*. Suspicious case of epidural hematoma due to coagulopathy caused by vitamin K deficiency associated with antibiotics. *Masui* 2007; **56**: 181–5.
18. Kumar, Neeraj. Nutritional neuropathies. *Neurol Clin* 2007; **25**: 209–55.
19. Chang GC, Adams-Huet B, *et al*. Acute Post-Gastric Reduction Surgery (APGARS) neuropathy. *Obes Surg* 2004; **14**: 182–9.
20. Singh S, Kumar A. Wernicke encephalopathy after obesity surgery. *Neurology* 2007; **68**: 807–11.
21. Charness ME, So YT. Wernicke's encephalopathy. *Uptodate* 2008. www.uptodate.com (Accessed 11/21/2008).
22. Donnino MW, Vega J, Miller J, *et al*. Myths and misconceptions of Wernicke's encephalopathy: What every emergency physician should know. *Ann Emer Med* 2007; **50**: 715–21.
23. Schrier SL. Etiology and clinical manifestations of vitamin B12 and folic acid deficiency. *Uptodate* 2008. www.uptodate.com (Accessed 11/19/2008)
24. Schrier SL. Diagnosis and treatment of vitamin B12 deficiency. *Uptodate* 2008. www.uptodate.com (Accessed 11/10/2008).
25. Lindenbaum J, Healton EB. Neuropsychiatric disorders caused by cobalamin deficiency in the absence of anemia or macrocytosis. *N Eng J Med* 1988; **318**: 1720–28.
26. Toh BH, Van Driel IR, *et al*. Pernicious anemia. *N Engl J Med* 1997; **337**: 1441–8.
27. Vasconcelos OM, Poehm EH, *et al*. Potential outcome factors in subacute combined degeneration: review of observational studies. *J Gen Intern Med* 2006; **21**: 1063–68.
28. Stacy CB, Di Rocco A, *et al*. Methionine in the treatment of nitrous-oxide-induced neuropathy and myeloneuropathy. *J Neurol* 1992; **239**: 401–3.
29. Lever EG, Elwes RDC, *et al*. Subacute combined degeneration of the cord due to folate deficiency: response to methyl folate treatments. *J Neurol Neurosurg Psychiatry* 1986; **49**: 1203–7.
30. Boan J, Mun EC. Management of patients after bariatric surgery. *Uptodate* 2008. www.uptodate.com (Accessed 10/22/2008).
31. Nguyen NT, Wilson SE. Complications of antiobesity surgery. *Nat Clin Pract Gastroenterol Hepatol* 2007; **4**: 138–47.
32. Podnos YD, Jimenez JC, *et al*. Complication after laparoscopic gastric bypass: a review of 3464 cases. *Arch Surg* 2003; **138**: 957–61.
33. Bult MJ, Van Dalen T. Surgical treatment of obesity. *Eu J Endocrinol* 2008; **158**: 135–45.
34. Elias WJ, Pouratian N, *et al*. Peroneal neuropathy following successful bariatric surgery. *J Neurosurg* 2006; **105**: 631–5.
35. Macgregor AM, Thoburn EK. Meralgia paresthetica following bariatric surgery. *Obes Surg* 1999; **9**: 364–8.
36. Lascano CA, Szomstein S, *et al*. Diabetes mellitus – associated diffuse autonomic dysfunction causing debilitating hypotension manifested after rapid weight

loss in a morbidly obese patient: case report and review of literature. *Surg Obes Relat Dis* 2005; **1**: 443–6.

37. Rubinshtein R, Ciubotaru M, Elad H, *et al*. Severe orthostatic hypotension following weight reduction surgery. *Arch Intern Med* 2001; **161**: 2145–7.
38. Kaufmann H. Neurally mediated syncope and syncope due to autonomic failure: differences and similarities. *J Clin Neurophysiol* 1997; **14**: 183–96.
39. Sarwer DB, Thompson JK, *et al*. Psychological considerations of the bariatric surgery patient undergoing body contouring surgery. *Plast Reconstr Surg* 2008; **121**: 423e–34e.
40. Sarwer DB, Fabricatore AN. Psychiatric considerations of the massive weight loss patient. *Clin Plastic Surg* 2008; **35**: 1–10.
41. Buchwald H, Avidor Y, *et al*. Bariatric surgery: A systemic review and meta-analysis. *JAMA* 2005; **292**: 1724–37.
42. Mathier MA, Zhang J. Dramatic functional improvement following bariatric surgery in a patient with pulmonary hypertension and morbid obesity. *Chest* 2008; **133**: 789–92.
43. Lee A, Fleisher J, Beckman A, *et al*. ACC/AHA 2007 Guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery. *Circulation* 2007; **116**: e418–e500.
44. Brodsky JB, Lemmens HJM, *et al*. Morbid obesity and tracheal intubation. *Anesth Analg* 2002; **94**: 732–6.
45. Sise A, Friedenberg FK. A comprehensive review of gastroesophageal reflux disease and obesity. *Obes Rev* 2008; **9**: 194–203.
46. Kocian R, Spahn DR. Bronchial aspirations in patients after weight loss due to gastric banding. *Anesth Analg* 2005; **100**: 1856–7.
47. Jean J, Compère V. The risk of pulmonary aspiration in patients after weight loss due to bariatric surgery. *Anesth Analg* 2008; **107**: 1257–9.

Chapter 22

Bariatric outcomes

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22.1 Introduction

Morbid obesity is the leading cause of preventable death in the United States [1]. Rising rates of obesity are seen in both men and women, and in all major racial, ethnic, and socioeconomic groups [2]. Morbid obesity reduces life expectancy by 5–20 years, and for the first time in history, it is predicted that the current generation may have a shorter life expectancy than the last [3, 4]. The only effective and enduring treatment for morbid obesity remains bariatric surgery. Since 1997, the number of bariatric surgical procedures in the United States has grown seven-fold as evidence has proven their safety and efficacy [5]. A clear reason for the recent growth of bariatric surgery was the approval in 2004 of weight loss surgery by the Centers for Medicare and Medicaid Services. This decision was driven by outcomes studies [6]. In the 1970s, serious adverse outcomes associated with jejunoileal bypass led to its ultimate demise, becoming the only operation to be banned by the Food and Drug Administration [7]. Currently, both strong consumer and insurer interest in weight loss surgery and increased societal awareness of patient safety has directed intense interest of bariatric surgery outcomes.

22.2 Data sources

Many efforts have been made to collect data for bariatric surgery by individual surgeons, surgical societies, and by research initiatives including the International Bariatric Surgery Registry, Society for Advanced Gastrointestinal Endoscopic Surgery (SAGES) Outcomes Initiative, Swedish Obese Subjects (SOS) trial, and the ongoing National Institutes of Health Longitudinal Assessment of Bariatric Surgery (LABS) trial [8–14]. Bariatric surgery outcomes have also been reported from existing administrative claims data such as Medicare, Nationwide In-Patient Sample (NIS), and University Health Consortium (UHC) [12–14].

A PubMed query including the search terms of "surgery", "weight loss" and "outcomes" yielded 465 results [15]. Evaluation of these different data sources should be upon evidence-based criteria. For example, prospective, clinically derived data through standardized definitions are clearly ideal. However, prospective data takes time to collect, and emerging trends of care may not be scrutinized until deleterious effects have already taken place. Administrative, claims data similar to what exists in Medicare, NIS, or UHC provide the advantage of easily obtainable data in large numbers that are multi-institutional. In addition, for certain rare procedures like adolescent bariatric surgery, administrative databases may be the only means of determining procedure trends in sizable numbers. However, these databases can provide conflicting results. Data are not obtained for clinical practice but for billing purposes. The clear shortcomings of administrative claims data are that they are deficient in clinical data such as BMI, which are integral for risk adjustment. While these claims data do not always render a definitive conclusion, they can serve as an early warning system regarding emerging trends in practice patterns and outcomes.

22.3 Outcomes: Weight loss

The degree of weight loss associated with bariatric surgery is dependent upon which operation is employed. Recently, several studies have provided considerable information regarding weight loss after surgery. In the SOS study, which compared medically and surgically treated obese patients, there were striking differences between the two groups regarding weight loss [16]. At 10 years the conventionally treated group had a 1.6% increase in total weight while the surgically treated group saw a 24% decrease in total weight. Among the different surgical procedures performed in the SOS

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study, the greatest total weight loss was associated with gastric bypass (RYGB) (25%), followed by vertical banded gastroplasty (VBG) (17%) and adjustable gastric banding (LAGB) (13%).

Two meta-analyses provide strong validation for the efficacy of weight loss surgery. Buchwald found that the degree of weight loss is lowest for restrictive procedures and highest for malabsorptive procedures [17]. In this meta-analysis of 22 094 patients (mean age: 47 years, mean BMI 46.9 kg m^{-2}, 72.6 % women), the mean percentage of excess weight loss was 61.2% for all patients. Excessive weight loss was higher for patients who underwent RYGB (61.6%) or VGB (68.2%) compared with those who received LAGB (47.5%). Similar results were reported by Maggard [18]. In this study, weight loss in kilograms at a minimum of 3 years postoperatively was as follows: LAGB (35 kg), VGB (32 kg), biliopancreatic diversion/duodenal switch (PBDS) (53 kg), and RYGB (42 kg).

It is clear that weight loss surgery leads to profound weight loss that varies by type of surgery. The weight loss engendered by bariatric surgery also leads to numerous down-stream benefits including co-morbidity resolution, quality of life improvement, and increased life span.

22.4 Outcomes: Comorbidity resolution

Weight loss surgery is a singular medical intervention that has the unique ability to reverse or improve the numerous medical conditions associated with obesity.

The leading cause of death in the United States remains heart and stroke disease, with 300 000 patients dying annually. The primary medical conditions contributing to this devastating human toll are diabetes, hypertension, and hyperlipidemia. These three co-morbidities, along with visceral obesity, constitute the metabolic syndrome, which is a strong risk factor for cardiovascular mortality. All three of these cardiovascular risk factors improved with laparoscopic RYGB with the following resolution rates: diabetes (82%), hypertension (70%), and hyperlipidemia (63%) [19].

The SOS study provided further demonstration of the benefits of bariatric surgery. At 10 years surgically treated obese patients had substantial improvements in their cardiac risk factors compared to non-surgically treated obese patients. Surgically treated patients had 25% reduction in hypertension, 43% improvement in high density lipoprotein, and 75% reduction in diabetes in comparison to the medically treated group. Another study found clear, consistent, and convincing resolution of every conventional risk factor at 1 year after gastric bypass surgery [20].

All weight loss procedures promote resolution of medical problems. Each procedure has a different degree of improvement for different co-morbidities [18]. For diabetes the following resolution rates were reported: LAGB (48%), VGB (68%), RYGB (84%), and BPDS (98%). Hyperlipidemia, another cardiac risk factor, also improved by different amounts: LAGB (71%), VGB (81%), RYNGB (94%), and BPDS (99%). Finally, hypertension resolved by the following rates: LAGB (38%), VBG (73%), RYGB (75%), and BPDS (81%).

Beyond the tremendous improvement in cardiac risk factors, weight loss surgery also provides enormous enhancement of the myriad medical problems that obesity engenders. Weight loss surgery improves sleep apnea as follows: LAGB (95%), VBG (77%), RYGB (87%), and BPDS (95%) [18]. After RYGB, patients had significantly fewer sleep disturbances with regard to falling asleep, insomnia, and feeling rested upon awakening [21].

Joint disease in obesity severely decreases both personal satisfaction and work productivity. Schauer demonstrated 88% resolution or improvement of joint disease for MO patients undergoing laparoscopic RYGB [19].

In addition to benefiting from decreased mortality, bariatric patients benefit from decreased morbidity. Prior to surgery, MO patients report significantly more symptoms of abdominal distress, including pain, gnawing sensations, nausea, vomiting, and abdominal distention than do normal controls. After RYGB, these symptoms are reduced to levels comparable with normal controls [21, 22]. Irritable bowel syndrome (IBS) is a constellation of symptoms, including abdominal pain or discomfort, altered bowel habits (diarrhea, constipation), increased flatus, and bloating/distention. Pre-operative MO patients rated the severity of IBS symptoms significantly higher than controls. Following RYGB, these same MO patients rate the severity of their symptoms significantly lower than pre-operatively and at levels equivalent to control patients [21, 22]. The leading digestive health complaint, gastroesophageal reflux disease, is cured or improved at a 96% rate [19]. The only gastrointestinal symptom which is worse following RYGB is dysphasia, which is common in MO patients who experience increased intra-abdominal pressure. Dysphasia may worsen following surgery from further increased

esophageal pressure due to overeating and overfilling of the restrictive small gastric pouch underscoring the importance of pre- and post-operative education regarding diet [21].

Non-alcoholic fatty liver disease (NAFLD) is also improved by weight loss surgery [23]. NAFLD comprises a histologic spectrum of fatty liver ranging from simple steatosis to portal fibrosis, non-alcoholic steatohepatitis (NASH), and cirrhosis [24]. The most advanced forms of NAFLD are closely associated with the metabolic syndrome, i.e., obesity and hypertension, hyper-triglyceridemia, and diabetes mellitus. NAFLD is the most prevalent liver disease in the United States [25, 26]. In a post-mortem series of obese non-drinkers, hepatic steatosis was present in 76% and NASH was present in 18.5% [27]. Evidence suggests that current bariatric surgical procedures may be beneficial in liver disease [23]. One study documented histologic improvements as measured by steatosis (89.7% improvement), hepatocellular ballooning (58.9% improvement), and centrilobular/perisinusoidal fibrosis (50% improvement) occur within a mean period of 18 months after RYGB. A diagnosis of NASH was made in 58.9% of MO patients pre-operatively and none were found to have NASH in post-operative liver biopsies [28].

Weight loss surgery has also been demonstrated to either eliminate or improve the following health conditions: venous stasis disease, gout, asthma, pseudotumor cerebri, urinary incontinence, and infertility [19].

22.5 Outcomes: Quality of life

Quality of life in the MO patient is clearly diminished due to poor self-image, economic discrimination, lack of medical access, and societal lack of acceptance. Of note, weight loss surgery is also equally powerful in improving quality of life as it is in resolving medical problems. The most accepted survey in medicine for measuring quality of life, the SF36 survey instrument, has been demonstrated to improve after bariatric surgery [30]. Pre-operatively, MO patients score significantly lower than United States population norms in the categories of general health, vitality, physical functioning, bodily pain, emotional, and social functioning. As soon as 3 months following RYGB, these same patients score no differently than United States norms in these categories [30]. Also, disease-specific quality of life instruments have also shown improvement after surgery [31]. A measure of depression, the Beck Depression Index, has been demonstrated to decline by half following weight loss surgery [32].

22.6 Outcomes: Complications

The risk of operative mortality and complications may temper some enthusiasm for bariatric surgery. Based on a meta-analysis by Maggard, mortality rates were dependent upon the specific procedure performed [18]. The average peri-operative mortality rates for the different procedures are: LAGB (0.4%, 0.01% to 2.1%); VGB (0.2%, 0% to 16.8%); RYGB (1%, 0.2% to 2.5%), and BPDS (0.9%, 0.01% to 1.3%) [18].

Complications of bariatric procedures include anastomotic leak or stenosis, pulmonary embolus, gastrointestinal bleeding, nutritional deficiencies, wound complications, bowel obstructions, ulcers, hernias, respiratory, cardiac, and implant device-related complications. Among the different surgical procedures, the rate of complications is proportional to the amount of weight loss produced by each operation: LAGB (7%), VBG (18%), RYGB (17%), and BPDS (38%) [18, 33].

Marginal ulcers are estimated to occur in 1–16% of RYGB patients, and perforated marginal ulcers occur in as many as 1% of RYGB patients [34, 35]. Ulcer perforation is linked to smoking, and use of non-steroidal anti-inflammatory drugs or glucocorticoids [36]. The use of non-absorbable sutures, as opposed to absorbable sutures, for the inner layer of the gastrojejunal anastomosis is associated with increased ulcer incidence [37]. The presence of *H. pylori* also increases risk for marginal ulcers [38]. It is common practice for bariatric surgeons to include a 6-month post-operative period of ulcer prophylaxis using proton pump inhibition.

Nutritional and vitamin deficiencies, and electrolyte abnormalities occur in 16.9% of RYGB patients and 2.5% of patients having VBG [18]. Patients who do not take daily vitamins post-operatively or patients who experience frequent vomiting are at an increased risk of developing such deficiencies, most common of which are protein, iron, vitamin B_{12}, folate, calcium, and the fat-soluble vitamins A, D, E, and K [39].

The parietal cells of the stomach produce intrinsic factor which is necessary for vitamin B_{12} absorption in the terminal ileum. Patients who undergo RYGB may develop B_{12} deficiency because RYGB separates the parietal cells in the fundus of the stomach from the smaller gastric pouch. There is therefore no contact between ingested food and intrinsic factor until the intersection of the Roux limb in the jejunum [40, 41]. In addition, often following RYGB the parietal cells of the stomach cease to produce intrinsic factor presumably because the fundus no longer has any contact with food [42]. It has been shown that restrictive bariatric surgery does not

cause vitamin B_{12} deficiency because the parietal cells in the fundus of the stomach remain attached [43].

Fat-soluble vitamin deficiencies are most often seen following BPDS operations because food has very little exposure to biliary and pancreatic secretions necessary for fat digestion, and there is little exposure of food to the ileum, where fat is normally absorbed. Calcium and folate deficiency can occur because they are absorbed in the duodenum and proximal jejunum. These segments of the digestive track are commonly bypassed in RYGB and PBDS surgery. The fat-soluble vitamin D is necessary for calcium absorption, and so vitamin D deficiency will further contribute to any calcium deficiency [39]. Thiamine deficiency may lead to Wernicke's encephalopathy, a syndrome of confusion, ataxia, opthalmoplegia, and impaired short-term memory. If thiamine deficiency is suspected, the patient should be given IV or IM thiamine immediately to increase the chances of symptom resolution [44].

Meta-analysis demonstrates that gastroesophageal reflux occurs post-operatively in 10.9% of RYGB, 2.2% of VBG, and 4.7% of LAGB patients [18]. Approximately one half of LAGB patients will experience some degree of heartburn and acid regurgitation [45]. Pseudoachalasia and esophageal dysmotility are late complications of LAGB and usually reverse upon removal of the gastric band [46]. The opposite problem can be seen among RYGB patients for whom post-operative dysphagia is significantly worse than normal weight controls, but not significantly worse than the patient's matched pre-operative symptoms [21].

A high incidence of gallstone formation has been documented with calorie induced weight loss [47]. A daily dose of 600 mg ursodiul for the first 6 months after surgery reduces the incidence of gallstones to 2% [48]. It is therefore recommended that all bariatric patients take ursodiol for 6 months post-operatively to reduce this largely preventable complication.

Beyond the type of procedure, the identified risk factors for complications after bariatric surgery include older age, male gender, high BMI, co-morbidities, and Medicare insurance status [20, 49–52]. The increased risk for Medicare patients is beyond just age since eligibility for Medicare is disability which may affect outcomes. Although patients with the most risk factors carry the highest risk for surgery, they also may derive the most benefit from bariatric surgery [53]. Of note, complications may not affect long-term weight loss, which is the outcome that best predicts long-term mortality risk[54].

22.7 Outcomes: Cost-effectiveness

Given the dramatic effects upon co-morbidities that bariatric surgery renders, it is apparent that bariatric surgery can also provide reduction in healthcare costs. This reduction in healthcare costs has been demonstrated in the province of Quebec, Canada, where surgically treated patients incurred $6000 CN less in healthcare costs versus MO patients treated non-surgically [55]. Two cost effectiveness analyses demonstrated that bariatric surgery is a dominant strategy with a range of $5000–$35 600 per Quality Adjusted Life Year (QALY) [56, 57]. Both these studies show that bariatric surgery provides a QALY at a lower rate than $50 000, the common marker of cost-effectiveness.

22.8 Outcomes: Survival benefit

Weight loss and co-morbidity resolution each contribute to increased survival for the surgically treated MO patient. Flum and Dellinger noted a 33% reduction in mortality for MO patients who underwent surgery versus MO patients who were treated medically [58]. MacDonald *et al.* also provided clear evidence for a survival benefit in the surgically treated MO patient [59]. This retrospective analysis of type 2 diabetic patients with morbid obesity who underwent either RYGB or did not undergo surgery demonstrated a mortality rate of only 9% in the surgical group during the 9 year follow-up compared with 28% in the non-surgical control group [60]. A decisive conclusion regarding the survival benefit conferred by RYGB is provided by a population-based study from Quebec, Canada [61]. The mortality rate in the bariatric surgery cohort was 0.68% compared with 6.17% in controls, an 89% reduction in the relative risk of death.

A retrospective cohort study of 9949 RYGB patients matched to 9628 severely obese controls found that surgery reduced the adjusted long-term mortality from any cause of death by 40% [62]. Among RYGB patients, mortality was decreased 56% from coronary artery disease, 92% from diabetes, and 60% from cancer. The decrease in cancer mortality was shown by another study to be related to a 14% decrease in cancer incidence among patients who underwent RYGB [63]. The greatest reductions in cancer incidence were among those considered obesity related, including esophageal adenocarcinomas (2% reduction), colorectal (30% reduction), post-menopausal breast (4%), uterine (78%), non-Hodgkin lymphoma (27%), and multiple myeloma (54%) [63]. The lower cancer risk

of patient's post-RYGB was presumably due to weight loss. Furthermore, once obese patients lose weight they may have better access to needed health surveillance like Pap Smears and colonoscopy. Finally, since increased BMI is associated with poorer surgical oncologic outcomes, it may be that with weight loss a better surgical outcome may be anticipated.

Overall, bariatric surgery dramatically improves survival and decreases mortality from all *disease-related* causes of death. Only the rate of non-disease caused deaths, including deaths resulting from accidents and suicide, increased after bariatric surgery and were 58% higher in the RYGB patients [62]. Higher accident and suicide rates in the surgical group may be related to alcohol abuse. One study demonstrated altered alcohol metabolism after gastric bypass surgery perhaps accounting for a propensity for alcohol abuse [30]. A study of bariatric surgery candidates found that 9% reported attempted suicide and 19% reported alcohol abuse pre-operatively [64]. There is concern that this vulnerable patient population has additional difficulty with the psychologic adjustments to weight loss which supports the need for psychological counseling before and after surgery [65, 66].

Sjostrom and colleagues in the SOS study demonstrated a reduction in mortality for surgically treated MO patients versus controls. The SOS study considered three different surgical techniques with 10 year post-surgical follow-up data. Adams *et al.* also showed a survival benefit after gastric bypass surgery. Using data from the state of Utah, 7925 surgical patients and 7925 severely obese control subjects were matched for age, sex, and BMI [62]. During a mean follow-up of 7 years, adjusted long-term mortality from any cause in the surgery group decreased by 40% compared with that in the control group. Cause-specific mortality in the surgery group decreased by 56% for coronary artery disease, by 92% for diabetes, and by 60% for cancer. However, rates of death not caused by disease, such as accidents and suicide, were 58% higher in the surgery group. Again, a common denominator to both accidents and suicides is alcohol abuse, and it has been demonstrated that gastric bypass profoundly alters alcohol metabolism [67]. There is clear and consistent data to support that bariatric surgery renders a survival benefit to the MO patient.

22.9 The volume effect and the Center of Excellence Movement

Many of the cited studies regarding morbidity and mortality were completed prior to improvements in current surgical technique [30]. In addition, surgeon and hospital experience can mitigate the risks associated with weight loss surgery. The most protective factor lowering complications is surgeon and hospital [53, 68–70]. Clearly, there is a benefit in having this complex and demanding surgery performed by experienced and committed surgeons operating in a dedicated healthcare facility. Having RYGB surgery by a high-volume surgeon in a high-volume hospital lead to decreased morbidity and mortality [53, 68–70].

In the United States, this volume outcome effect has been recognized by the Centers for Medicare and Medicaid Services that now require Medicare patients to undergo surgery only at Bariatric Surgery Centers of Excellence [9]. Numerous criteria are needed to qualify as a Bariatric Surgery Center of Excellence, but the primary one is a surgeon performing more than 50 cases and hospital volume exceeding 125 cases annually. While a referral to a Bariatric Surgery Center of Excellence may lead to decreased morbidity and mortality, this referral pattern must be balanced with appropriate and sufficient access to care for a vulnerable population without other therapeutic options.

22.10 Conclusions

Obesity is a worldwide epidemic with serious medical consequences. The only effective and enduring therapy for morbid obesity is bariatric surgery. Bariatric surgery reduces mortality, leads to sustained weight loss, and improves patient quality of life and improves all obesity-related co-morbidites, Rates of post-operative complications can be reduced with proper preventative measures. Weight-loss surgery is most effective with proper patient selection and an appropriately trained surgical team. Risks of weight-loss surgery can be mitigated by experience and patient selection, education, and lifelong surveillance.

References

1. Parikh NI, Pencina MJ, Wang TJ, *et al*. Increasing trends in incidence of overweight and obesity over 5 decades. *Am J Med* 2007; **120**: 242–50.
2. Mokdad AH, Bowman BA, Ford ES, Vinicor F, Marks JS, Koplan JP. The continuing epidemics of obesity and diabetes in the United States. *JAMA* 2001; **286**: 1195–200.
3. Fontaine KR, Redden DT, Wang C, Westfall AO, Allison DB. Years of life lost due to obesity. *JAMA* 2003; **289**: 187–93.
4. Olshansky SJ, Passaro DJ, Hershow RC, *et al*. A potential decline in life expectancy in the United States in the 21st century. *N Engl J Med* 2005; **352**: 1138–45.

5. Santry HP, Gillen DL, Lauderdale DS. Trends in bariatric surgical procedures. *JAMA* 2005; **294**: 1909–17.
6. Centers for Medicare and Medicaid Services. Decision Memo for Bariatric Surgery for the Treatment of Morbid Obesity (CAG-00250R). Available at http://www.cms.hhs.gov. (Accessed 2/2008.)
7. Griffen WO, Jr., Young VL, Stevenson CC. A prospective comparison of gastric and jejunoileal bypass procedures for morbid obesity. *Ann Surg* 1977; **186**: 500–9.
8. Zhang W, Mason EE, Renquist KE, Zimmerman MB. Factors influencing survival following surgical treatment of obesity. *Obes Surg* 2005; **15**: 43–50.
9. Nguyen NT, Morton JM, Wolfe BM, Schirmer B, Ali M, Traverso LW. The SAGES Bariatric Surgery Outcome Initiative. *Surg Endosc* 2005; **19**: 1429–38.
10. Sjostrom L, Narbro K, Sjostrom CD, *et al*. Effects of bariatric surgery on mortality in Swedish obese subjects. *N Engl J Med* 2007; **357**: 741–52.
11. Belle SH, Berk PD, Courcoulas AP, *et al*. Safety and efficacy of bariatric surgery: Longitudinal assessment of bariatric surgery. *Surg Obes Relat Dis* 2007; **3**: 116–26.
12. Flum DR, Salem L, Elrod JA, Dellinger EP, Cheadle A, Chan L. Early mortality among Medicare beneficiaries undergoing bariatric surgical procedures. *JAMA* 2005; **294**: 1903–8.
13. Trus TL, Pope GD, Finlayson SR. National trends in utilization and outcomes of bariatric surgery. *Surg Endosc* 2005; **19**: 616–20.
14. Varela JE, Hinojosa MW, Nguyen NT. Perioperative outcomes of bariatric surgery in adolescents compared with adults at academic medical centers. *Surg Obes Relat Dis* 2007; **3**: 537–40; discussion 41–2.
15. http://www.ncbi.nlm.nih.gov.laneproxy.stanford.edu/sites/entrez. (Accessed 4/12/ 2008.)
16. Sjostrom L, Lindroos AK, Peltonen M, *et al*. Lifestyle, diabetes, and cardiovascular risk factors 10 years after bariatric surgery. *N Engl J Med* 2004; **351**: 2683–93.
17. Buchwald H. The future of bariatric surgery. *Obes Surg* 2005; **15**: 598–605.
18. Maggard MA, Shugarman LR, Suttorp M, *et al*. Meta-analysis: surgical treatment of obesity. *Ann Intern Med* 2005; **142**: 547–59.
19. Schauer PR, Ikramuddin S, Gourash W, Ramanathan R, Luketich J. Outcomes after laparoscopic Roux-en-Y gastric bypass for morbid obesity. *Ann Surg* 2000; **232**: 515–29.
20. Williams DB, Hagedorn JC, Lawson EH, *et al*. Gastric bypass reduces biochemical cardiac risk factors. *Surg Obes Relat Dis* 2007; **3**: 8–13.
21. Clements RH, Gonzalez QH, Foster A, *et al*. Gastrointestinal symptoms are more intense in morbidly obese patients and are improved with laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2003; **13**: 610–4.
22. Foster A, Laws HL, Gonzalez QH, Clements RH. Gastrointestinal symptomatic outcome after laparoscopic Roux-en-Y gastric bypass. *J Gastrointest Surg* 2003; **7**: 750–3.
23. Klein S, Mittendorfer B, Eagon JC, *et al*. Gastric bypass surgery improves metabolic and hepatic abnormalities associated with nonalcoholic fatty liver disease. *Gastroenterology* 2006; **130**: 1564–72.
24. Abrams GA, Kunde SS, Lazenby AJ, Clements RH. Portal fibrosis and hepatic steatosis in morbidly obese subjects: A spectrum of nonalcoholic fatty liver disease. *Hepatology* 2004; **40**: 475–83.
25. Dixon JB, Bhathal PS, O' Brien PE. Nonalcoholic fatty liver disease: predictors of nonalcoholic steatohepatitis and liver fibrosis in the severely obese. *Gastroenterology* 2001; **121**: 91–100.
26. Barker KB, Palekar NA, Bowers SP, Goldberg JE, Pulcini JP, Harrison SA. Non-alcoholic steatohepatitis: effect of Roux-en-Y gastric bypass surgery. *Am J Gastroenterol* 2006; **101**: 368–73.
27. Wanless IR, Lentz JS. Fatty liver hepatitis (steatohepatitis) and obesity: an autopsy study with analysis of risk factors. *Hepatology* 1990; **12**: 1106–10.
28. Liu X, Lazenby AJ, Clements RH, Jhala N, Abrams GA. Resolution of nonalcoholic steatohepatits after gastric bypass surgery. *Obes Surg* 2007; **17**: 486–92.
29. Buchwald H, Avidor Y, Braunwald E, *et al*. Bariatric surgery: a systematic review and meta-analysis. *JAMA* 2004; **292**: 1724–37.
30. Nguyen NT, Goldman C, Rosenquist CJ, *et al*. Laparoscopic versus open gastric bypass: a randomized study of outcomes, quality of life, and costs. *Ann Surg* 2001; **234**: 279–89; discussion 89–91.
31. Dymek MP, Le Grange D, Neven K, Alverdy J. Quality of life after gastric bypass surgery: a cross-sectional study. *Obes Res* 2002; **10**: 1135–42.
32. Dixon JB, Dixon ME, O'Brien PE. Depression in association with severe obesity: changes with weight loss. *Arch Intern Med* 2003; **163**: 2058–65.
33. Inge TH, Krebs NF, Garcia VF, *et al*. Bariatric surgery for severely overweight adolescents: concerns and recommendations. *Pediatrics* 2004; **114**: 217–23.
34. Dallal RM, Bailey LA. Ulcer disease after gastric bypass surgery. *Surg Obes Relat Dis* 2006; **2**: 455–9.
35. Higa KD, Boone KB, Ho T. Complications of the laparoscopic Roux-en-Y gastric bypass: 1,040 patients – what have we learned? *Obes Surg* 2000; **10**: 509–13.
36. Felix EL, Kettelle J, Mobley E, Swartz D. Perforated marginal ulcers after laparoscopic gastric bypass. *Surg Endosc* 2008; **22**: 2128–32.
37. Sacks BC, Mattar SG, Qureshi FG, *et al*. Incidence of marginal ulcers and the use of absorbable anastomotic

sutures in laparoscopic Roux-en-Y gastric bypass. *Surg Obes Relat Dis* 2006; **2**: 11–6.

38. Rasmussen JJ, Fuller W, Ali MR. Marginal ulceration after laparoscopic gastric bypass: an analysis of predisposing factors in 260 patients. *Surg Endosc* 2007; **21**: 1090–4.
39. Bloomberg RD, Fleishman A, Nalle JE, Herron DM, Kini S. Nutritional deficiencies following bariatric surgery: what have we learned? *Obes Surg* 2005; **15**: 145–54.
40. Skroubis G, Sakellaropoulos G, Pouggouras K, Mead N, Nikiforidis G, Kalfarentzos F. Comparison of nutritional deficiencies after Roux-en-Y gastric bypass and after biliopancreatic diversion with Roux-en-Y gastric bypass. *Obes Surg* 2002; **12**: 551–8.
41. Coupaye M, Puchaux K, Bogard C, *et al*. Nutritional consequences of adjustable gastric banding and gastric bypass: a 1-year prospective study. *Obes Surg* 2009; **19**: 56–65.
42. Marcuard SP, Sinar DR, Swanson MS, Silverman JF, Levine JS. Absence of luminal intrinsic factor after gastric bypass surgery for morbid obesity. *Dig Dis Sci* 1989; **34**: 1238–42.
43. Cooper PL, Brearley LK, Jamieson AC, Ball MJ. Nutritional consequences of modified vertical gastroplasty in obese subjects. *Int J Obes Relat Metab Disord* 1999; **23**: 382–8.
44. Aasheim ET. Wernicke encephalopathy after bariatric surgery: a systematic review. *Ann Surg* 2008; **248**: 714–20.
45. Gustavsson S, Westling A. Laparoscopic adjustable gastric banding: complications and side effects responsible for the poor long-term outcome. *Semin Laparosc Surg* 2002; **9**: 115–24.
46. Facchiano E, Scaringi S, Sabate JM, *et al*. Is esophageal dysmotility after laparoscopic adjustable gastric banding reversible? *Obes Surg* 2007; **17**: 832–5.
47. Shiffman ML, Sugerman HJ, Kellum JM, Brewer WH, Moore EW. Gallstone formation after rapid weight loss: a prospective study in patients undergoing gastric bypass surgery for treatment of morbid obesity. *Am J Gastroenterol* 1991; **86**: 1000–05.
48. Sugerman HJ, Brewer WH, Shiffman ML, *et al*. A multicenter, placebo-controlled, randomized, double-blind, prospective trial of prophylactic ursodiol for the prevention of gallstone formation following gastric-bypass-induced rapid weight loss. *Am J Surg* 1995; **169**: 91–6; discussion 6–7.
49. Benotti PN, Wood GC, Rodriguez H, Carnevale N, Liriano E. Perioperative outcomes and risk factors in gastric surgery for morbid obesity: a 9-year experience. *Surgery* 2006; **139**: 340–6.
50. Livingston EH, Huerta S, Arthur D, Lee S, De Shields S, Heber D. Male gender is a predictor of morbidity and age a predictor of mortality for patients undergoing gastric bypass surgery. *Ann Surg* 2002; **236**: 576–82.
51. Livingston EH, Langert J. The impact of age and Medicare status on bariatric surgical outcomes. *Arch Surg* 2006; **141**: 1115–20; discussion 21.
52. Morton J, Hagedorn J, Encarnacion B, *et al*. Post-operative gastric bypass complications do not affect weight loss, 11th Annual IFSO Meeting Sydney, Australia, August 2006.
53. Wolfe BM, Morton JM. Weighing in on bariatric surgery: procedure use, readmission rates, and mortality. *JAMA* 2005; **294**: 1960–3.
54. Alvarado R, Alami RS, Hsu G, *et al*. The impact of preoperative weight loss in patients undergoing laparoscopic Roux-en-Y gastric bypass. *Obes Surg* 2005; **15**: 1282–6.
55. Sampalis JS, Liberman M, Auger S, Christou NV. The impact of weight reduction surgery on health-care costs in morbidly obese patients. *Obes Surg* 2004; **14**: 939–47.
56. Clegg A, Colquitt J, Sidhu M, Royle P, Walker A. Clinical and cost effectiveness of surgery for morbid obesity: a systematic review and economic evaluation. *Int J Obes Relat Metab Disord* 2003; **27**: 1167–77.
57. Craig BM, Tseng DS. Cost-effectiveness of gastric bypass for severe obesity. *Am J Med* 2002; **113**: 491–8.
58. Flum DR, Dellinger EP. Impact of gastric bypass operation on survival: a population-based analysis. *J Am Coll Surg* 2004; **199**: 543–51.
59. MacDonald KG, Jr., Long SD, Swanson MS, *et al*. The gastric bypass operation reduces the progression and mortality of non-insulin-dependent diabetes mellitus. *J Gastrointest Surg* 1997; **1**: 213–20; discussion 20.
60. Lean ME, Powrie JK, Anderson AS, Garthwaite PH. Obesity, weight loss and prognosis in type 2 diabetes. *Diabet Med* 1990; **7**: 228–33.
61. Christou NV, Sampalis JS, Liberman M, *et al*. Surgery decreases long-term mortality, morbidity, and health care use in morbidly obese patients. *Ann Surg* 2004; **240**: 416–23; discussion 23–4.
62. Adams TD, Gress RE, Smith SC, *et al*. Long-term mortality after gastric bypass surgery. *N Engl J Med* 2007; **357**: 753–61.
63. Adams TD, Stroup AM, Gress RE, *et al*. Cancer incidence and mortality after gastric bypass surgery. *Obesity (Silver Spring)* 2009; **17**: 796–802.
64. Sansone RA, Wiederman MW, Schumacher DF, Routsong-Weichers L. The prevalence of self-harm behaviors among a sample of gastric surgery candidates. *J Psychosom Res* 2008; **65**: 441–4.
65. Hsu LK, Benotti PN, Dwyer J, *et al*. Nonsurgical factors that influence the outcome of bariatric surgery: a review. *Psychosom Med* 1998; **60**: 338–46.
66. Waters GS, Pories WJ, Swanson MS, Meelheim HD, Flickinger EG, May HJ. Long-term studies of mental

health after the Greenville gastric bypass operation for morbid obesity. *Am J Surg* 1991; **161**: 154–7; discussion 7–8.

67. Hagedorn JC, Encarnacion B, Brat GA, Morton JM. Does gastric bypass alter alcohol metabolism? *Surg Obes Relat Dis* 2007; **3**: 543–8; discussion 8.
68. Nguyen NT, Paya M, Stevens CM, Mavandadi S, Zainabadi K, Wilson SE. The relationship between hospital volume and outcome in bariatric surgery at academic medical centers. *Ann Surg* 2004; **240**: 586–93; discussion 93–4.
69. Poulose BK, Griffin MR, Zhu Y, *et al*. National analysis of adverse patient safety for events in bariatric surgery. *Am Surg* 2005; **71**: 406–13.
70. Livingston EH, Ko CY. Assessing the relative contribution of individual risk factors on surgical outcome for gastric bypass surgery: a baseline probability analysis. *J Surg Res* 2002; **105**: 48–52.

Section 5
Chapter
23

Special topics

Organizing a bariatric team

Fawzi S. Khayat and Matthew M. Hutter

23.1 Introduction

As the number of weight loss operations has grown, so has the scrutiny on outcomes. Good outcomes are a result of comprehensive care initiated at the initial consultation and continuing and extending many years post-operatively. Successful outcomes require a well-organized team of caregivers. The National Institutes of Health, the Society of American Gastrointestinal and Endoscopic Surgeons, as well as the American Society for Metabolic and Bariatric Surgery (ASMBS) and the American College of Surgeons (ACS) have all advocated a multidisciplinary approach to the management of the MO patient. While the surgeon is the centerpiece of any successful bariatric program, a multitude of medical professionals is required. In addition to these essential staff members, a comprehensive bariatric program requires appropriate infrastructure, educational and support programs [1, 2].

23.2 Outpatient

Success, satisfaction and safety of bariatric procedures depend in large part on a commitment and partnership between patient and physician. As such, compassionate and thoughtful care is essential. All staff members interacting with the MO patient must be aware of the psychologic and social implications of this disease process and must treat the patients with respect. Sensitivity training for all members of the team can help increase awareness about prejudices that the MO patients may encounter [3].

Patient education is of paramount importance to ensure realistic expectations and to outline important lifestyle modifications. This is best achieved through educational seminars and reference materials [4]. This section will outline the different facets of outpatient care including patient education and support as well as bariatric team members and data collection.

23.2.1 Pre-operative educational workshop

All patients considering weight loss surgery undoubtedly have many questions. With the plethora of information available on the internet, as well as increasing television advertisements, patients will present with preconceived notions about surgical interventions, many of which may be inaccurate. Educational programs are necessary to inform patients of the various bariatric procedures, the expected post-operative course, and the dietary changes that are required after surgery. Furthermore, these seminars provide an opportunity to familiarize the patients with the overall scheme of the program including the pre-operative evaluation pathways. It also serves to introduce the patients to the staff members. Most importantly, seminars emphasize the need for lifelong follow up, and the need for continued assessment of nutritional parameters (Table 23.1).

Attendance to these seminars is very important and should be monitored prior to surgical intervention. It is important that ample time is left for questions and answers at the end of each seminar. Family members of patients are encouraged to attend. Audio visual and written material should be provided for independent study and review. A post seminar quiz can be helpful to ensure patient understanding of the key informational concepts.

In addition to providing written material to patients, a comprehensive bariatric program should have a dedicated website. This provides patients with a reliable source of information about the weight loss program including surgical options, the problems associated with obesity, as well as the pre- and post-operative pathways that patients will follow. This site would further familiarize the patients with the medical staff and can provide easy and reliable

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

Table 23.1 Pre-operative evaluation schedule

Patient history questionnaire
Attendance at an information seminar
Evaluation by a psychologist
Evaluation by a nutritionist
Evaluation by an internist
Evaluation by the surgeon
Evaluation by medical specialists as deemed necessary by the surgeon or medical staff: – Neurologist – Cardiologist – Pulmonologist – Gastroenterologist
Pre-operative anesthesia clearance
Final pre-operative surgical visit

communication. It can also function as a prescreening tool whereby patients can submit basic application forms electronically. Chat rooms and answers to frequently asked questions can be set up to further facilitate transfer of information.

23.2.2 Personnel

23.2.2.1 Surgeon

Bariatric surgeons, like other surgical sub-specialists, should have an in depth understanding of the discipline's unique cognitive, technical, and administrative challenges. The learning curve to safely perform weight-loss surgery is prolonged, and thus requires some form of specialized training [5, 6]. The ASMBS [7] and the ACS [8] have outlined guidelines for the credentialing of bariatric surgeons. In addition to having successfully completed a general surgery residency, surgeons who wish to independently perform weight-loss surgery should document the completion of 25 bariatric procedures with satisfactory outcomes under the supervision of an experienced bariatric surgeon [6, 8, 9]. This can be accomplished in a dedicated 1- or 2-year fellowship in bariatric and minimally invasive surgery or through mini-fellowships (1–2-month preceptorships) for those surgeons who are already in practice.

In addition to technical prowess, patient selection, work up and follow up is extremely important for a bariatric practice [2]. Ultimately the surgeon is responsible for the entire spectrum of care and should be an expert and overseer of all aspects of the multidisciplinary team. Of critical importance is a regimented short- and long-term follow-up program to ensure the continued success and health of the post-operative patient (Table 23.2).

23.2.2.2 Internist

Some bariatric programs have chosen to include internists specialized in obesity medicine to manage the medical co-morbidities of their patients. Currently the discipline of obesity medicine is small, but as the obesity epidemic continues to grow it is not unreasonable to expect a corresponding growth in these specialists. Regardless of the person responsible for medical management, attention to detail is essential in the perioperative care of the MO patient.

Many patients are not aware of all of their own morbidities. Sleep apnea, venous stasis, and hypercoagulable disorders are examples of such morbidities that should be evaluated in every patient [10]. Laboratory evaluation for iron, B_{12} and calcium should be performed prior to surgery as the absorption of these elements is decreased by the surgical procedure. Screening for *Helicobacter pylori* and biliary colic are other medical conditions that should to be deciphered prior to surgery as they may alter management. Diabetes mellitus is common in the MO, and careful glucose control is essential to allow for proper wound healing and a complication free recovery. Careful instructions should be given to diabetic patients on how to manage the dose and frequency of their diabetic medication pre- and post-operatively.

After bariatric surgery, patients experience significant changes in medical co-morbidities, and alterations in eating and physiologic feedback. It is necessary to modify many of the standard medical assessment techniques. A regimented follow-up program is necessary. It is recommended to follow up these patients every 4–6 weeks for the first 9 months and then annually thereafter. Follow-up visits should focus on evaluation and treatment of electrolyte, mineral and micronutrient deficiencies, medication management for co-morbidities, as well as nutritional assessment and counseling. It is necessary to recognize the interaction of psychosocial and medical issues and referral for emotional counseling should be done when necessary.

23.2.2.3 Psychologist

Bariatric surgery psychology is a specialty area requiring focused training or experience. Proper evaluation and follow up will be of critical benefit in enhancing patient compliance and improving long-term quality of life. Some programs employ a psychologist as part of the team, while others resource out to a local psychologist experienced in the evaluation of the MO patient.

The psychologic evaluation is initiated in the preoperative work-up. Screening for signs and symptoms

Table 23.2 Example of a post-operative follow-up schedule

Time after surgery	Provider	Reason for visit
7–10 days	Surgeon Dietician	Abdominal exam and wound evaluation Dietary advancement
1 month	Surgeon Internist Dietician	Assessment of progress and problems Medication follow-up Nutrition education
3 months	Internist Dietician	Review of health, medications and labs Vitamin and mineral supplementation adjustments Nutritional education
6 months	Surgeon Dietician	Assessment of progress and problems Nutritional education
9 months	Internist	Review of health and medications.
1 year	Surgeon Internist Dietician	Assessment of progress and problems Assessment of comorbidities & medications; review of labs Vitamin and mineral supplementation adjustments Nutritional education
Yearly Thereafter	Surgeon Internist	Assessment of progress and problems Assessment of comorbidities and medications

Psychologic follow up is provided to those patients who experience post-operative emotional difficulties. Support group meetings are scheduled bimonthly and patients are encouraged to attend.

that may indicate a patients' inability to comply with needed protocols and post-operative adjustment is essential. It is also important to ensure that patients have a realistic expectation of the rate of weight loss, as many expect it to be instantaneous. Continued care post-operatively is equally as important since counseling will help patients withstand the lifelong changes associated with surgical weight loss procedures. Accelerated weight loss can lead to emotional lability and may result in feelings of lethargy, depression, and other psychopathology. A significant number of patients discover that they are not capable of coping with their new persona as a thin person. These patients may require therapy to deal with issues of body image changes, past abuse, and relationships with intimate partners.

23.2.2.4 Dietician

It was initially thought that weight loss surgery exerted its affect through restrictive or malabsorptive means, but there is now growing understanding that predominant weight loss is a result of metabolic changes brought about by surgery. While most of these changes are beneficial, they also place the bariatric patient at an increased risk for malnutrition. It is therefore essential to ensure dietary compliance post-operatively through education, counseling, and through proper patient selection.

A significant number of individuals go into obesity surgery with pre-existing eating disorders. These patients either don't recognize the problem themselves or are unlikely to disclose these behaviors unless they are solicited. At the first encounter the dietician analyzes the patient's eating patterns and meal portions, and devises a plan that prepares the patient for the changes of weight loss surgery. In order to maintain the weight loss that typically follows surgery, patients have to change their eating patterns dramatically. This change in behavior must start in the pre-operative period. Patients who are either unable or unwilling to change their behaviors may not be suitable for weight loss surgery, and may benefit from referral to a psychologist to help unmask the underlying emotional issues associated with food.

Most vitamins and minerals are absorbed in the duodenum and proximal ileum and there are resultant deficiencies in these elements after bariatric surgery, particularly gastric bypass. Specific concerns include protein malnutrition, and deficiencies in vitamins B_1, B_6, and B_{12} as well as vitamin A, calcium, iron, and zinc [11]. The most effective therapy is supplementation and education. Dieticians have a crucial role in counseling patients about appropriate supplementation and guiding them through the series of specific dietary transitions after surgery.

In the post-operative period, patients typically have a significant decrease in appetite for up to 6 months after surgery. During this time, patients must adhere to a schedule for eating since they may not be prompted by hunger. Patients benefit from a well-outlined dietary plan including calorie counting and more importantly assessment of sufficient protein intake to ensure proper

healing and avoidance of detrimental malnutrition. The transition to solid food is difficult as many patients stray from the recommended nutrition guidelines, and try foods that appear attractive. Patients may also not recognize that certain foods cause vomiting and erroneously believe that their surgery was unsuccessful. Dietary counseling regarding appropriate food items and quantity is essential. An emphasis has to be placed on protein consumption and avoidance of high carbohydrate foods as they can cause dumping syndrome.

23.2.2.5 Program coordinator

A program coordinator occupies a central role in any bariatric program. This position is filled by a skilled professional (nurse, physician assistant, dietician, or office manager) familiar with the medical, psychological, and emotional needs of the bariatric patient and functions as a liaison between the patients and other staff members. In addition, they are capable of managing a variety of common post-surgical symptoms and able to recognize early signs of complications that require more intensive work up. They also communicate with hospital staff in regards to patient requirements and facilitate immediate post-operative care. Patients interact with the coordinator throughout the treatment process thereby developing a good rapport that is essential to success.

23.2.2.6 Support groups

Support groups are designed for post-operative patients to provide a safe and caring forum for discussing topics ranging from expectations to recovery. Patients can provide support for one another and help guide each other through difficult or frustrating times. These groups should be moderated by a healthcare professional familiar with the challenges and changes that these patients are facing thus functioning as a source of information and support while maintaining appropriate content. In addition to support, these meetings can provide education and motivation to its members. Discussions centered on food preparation advice, effective exercise programs, and individual accomplishments can help patients attain a feeling of solidarity. An occasional guest speaker can further increase the appeal and excitement of these meetings.

23.3 Bariatric surgery database

As with any surgical intervention, ensuring good outcomes with continued improvement and advancement is of ultimate importance. A database of patient demographic information, comorbidities, operative interventions, post-operative complications and follow up would be invaluable for both research and continuous quality improvement [12–14]. Though individual databases can provide a starting point for self scrutiny and quality improvement initiatives, nationwide databases can provide appropriate comparisons and benchmarks to more accurately assess the quality of care provided. The ASMBS [7] and the ACS [8] have both developed bariatric specific data collection systems to collect standardized, risk adjusted data on surgical outcomes, including long-term results.

23.4 Accreditation

Accreditation programs have been developed by the ASMBS and ASC Bariatric Surgery Center networks. We recommend that bariatric programs strive for accreditation. Formal accreditation is required for reimbursement by Centers of Medicare and Medicaid Services, as well as by many insurance companies. Both the ASMBS and ACS programs have a similar set of guidelines describing what constitutes a safe, effective, and well-organized bariatric surgical team. The process of accreditation can help to bring the team together to assure that all aspects of the multidisciplinary care are appropriately addressed.

23.5 Operating room

The pre-operative preparatory phase for weight loss surgery can often be lengthy and demanding for the MO patient. Thus there is a certain sense of relief when this day arrives, but it is also frequently accompanied by anxiety and apprehension. It is important that the patients are well educated on the structure of the operative day and more importantly have clear dietary and medication instructions to follow. The staff responsible for the pre-operative care of the bariatric patient needs to be familiar with routine protocols and have training to understand the psychologic conditions of these patients and their family. Sensitivity training for these team members can greatly increase awareness about prejudices that the MO patients may encounter [3].

Given that risk of gastric regurgitation is elevated in the obese, specific measures to prevent this should be implemented. We administer metoclopramide and H_2 receptor blockers before the administration of anesthesia. In addition, any premedications should be administered intravenously or orally in a monitored setting for safety. Attempts at intramuscular injection typically result in injection of adipose tissue with unpredictable results.

Of critical importance in ensuring a successful procedure is a skilled anesthesia team. Obesity affects every organ system and is the cause of many chronic medical conditions which complicate anesthetic care. The

bariatric anesthesiologist should be familiar with the steps of the operation as their assistance and awareness is valuable. It is essential that a skilled anesthesiologist is familiar with all the challenges of treating these high risk patients to ensure safe and successful intraoperative management. A comprehensive discussion of all the anesthetic considerations for the MO patient can be found in this book.

Surgical assistants as well as scrub and circulating nurses are also important for the successful completion of bariatric procedures. Familiarity with the specialized maneuvers and instrumentation is key to ensure smooth flow. There is a wide range of devices being used in weight loss surgery and careful accounting of loose parts is needed. These may include staplers, anvils, plastics pins, needles, and drains among others. A well-organized team requires that all operating room staff are in synchronization during the procedure and are able to follow the surgeon's lead when going through the different steps of the operation.

Design of the operating room should focus on accommodating a large person. An effective patient transfer system offering easy management without excessive strain on the team is essential. The surgery table should be sufficiently large and x-ray transparent. Tables should also possess accessories such as padded supports to protect vulnerable areas such as heels, buttocks, and shoulders along with the capability of six axis motion including Trendelenburg position. Foot boards are universally used to prevent slippage of the patient during operative maneuvering.

With respect to surgical equipment, extra long instruments including laparoscopes, trocars, graspers, and ultrasonic dissectors are occasionally necessary. In addition, cardiac defibrillators must be available in case of emergency use. Given that obese patients have an increased tendency for heat loss, central body temperature must be continually measured and heat applied through forced air systems as well as heated fluids. Blood sugar levels should be monitored routinely as many patients have insulin resistance. Deep venous thrombosis prophylaxis is essential and should include elastic stocking and/or sequential compression devices to promote lower extremity blood flow as well as heparin (fractionated or unfractionated). Endoscopy equipment should also be available to delineate anatomy and/or test for leaks.

23.6 Inpatient

With the introduction and continued improvement of laparoscopic techniques for weight loss surgery, there has been a dramatic decrease in the post-operative length of stay and the need for intensive care monitoring for the MO patient. Nonetheless, serious complication including anastomotic leaks, pulmonary embolisms, respiratory failure, and myocardial infarctions, still occur. A dedicated unit and a specialized staff of trained hospitalists, residents and nurses are invaluable for the early recognition of these post-operative problems. Availability of diagnostic and treatment facilities capable of accommodating these patients is important. These facilities include intensive care units, radiology, and cardiology suites [1].

Early ambulation is the cornerstone for post-operative recovery from weight loss surgery. Not only does it decrease the risk of thromboembolic disease, but also decreases the risk of respiratory complications. Ambulation, along with all post-operative activities of the obese patient, is greatly facilitated by a skilled nursing team. Nursing staff with special training to help with bathing, personal hygiene, venous puncture, and ambulation is important. In addition, staff well versed in the sensitivity issues of these patients is more capable of providing necessary emotional support that greatly helps the post-operative recovery of these patients. These considerations can be facilitated by creating a specialty ward for weight loss surgery patients where routine standardized care can be more easily implemented.

23.7 Infrastructure

A multidisciplinary team of specialists is required to care for the obese patient in the pre-operative evaluation as well as the post-operative phase [15]. Thus, the physical adaptations necessary to care for these patients must be in place in all the regions where the multidisciplinary team works. There are many models that are effective in designing this infrastructure and the following represents important considerations.

The clinic provides the first impression of the bariatric program and is also the place where patients spend the greatest deal of time in both the pre-operative work up and subsequent post-operative follow up. As such, it is important that clinic space is designed to accommodate the obese patient in terms of comfort and accessibility. In addition to temperature control, easy access to the reception area is essential, and preferably it should be located close to the parking garage. If the clinic is in a building, access to wide elevators able to accommodate hospital beds, scooters, and wheelchairs is important. Design of the reception area should emphasize the avoidance of steps, the presence of antiskid floors, and

handrail firmly secured to the floor to allow for greater weight tolerance.

Wide doorways, and access routes, including bathrooms and exam rooms, should be able to accommodate the passage of large patients as well as carts. Plentiful seating with oversized chairs in the reception area and doctor's offices will help accommodate the obese patients and their family members who are often involved in the preparatory phase. Weight scales should be capable of weighing patients up to 300 kg and be equipped with a height measurement tool to facilitate calculating the body mass index. Wheelchairs are important for transport. Exam room tables of sufficient size need to be equipped with hydraulic lifts to assist in positioning to facilitate physical examination. Large blood pressure cuffs should also be available.

Hospital accommodations should similarly be well designed with wide doors, oversized hospital beds with electronic controls, and large bathrooms with oversized showers and toilets. Handrail availability to assist in ambulation is necessary. Hospital clothing should be specifically designed to accommodate larger patients and easy to put on and remove. These accommodations should also be available in all hospital facilities where bariatric patients may be cared for.

23.8 Conclusions

The increase in the prevalence of obesity has contributed to an increase in bariatric surgery. As the number of procedures increases, so too does the scrutiny on outcomes. The health effects of obesity are far reaching, and can be seen not only in every organ system, but also socially and psychologically. As such, it makes sense that the treatment of this disease process should be multidisciplinary. A successful bariatric program will be comprised of specially trained and dedicated personnel who understand the nuances of obesity medicine and are capable of providing compassionate and comprehensive care. This team, led by the surgeon, must be coordinated and committed to the long-term treatment of the bariatric patient, and must focus on all aspects of care ranging from infrastructure to the emotional well-being of the patient.

References

1. de Sousa LH, Sardinha EL *et al*. Requirements of the clinic and institution. In: Pitombo C, Jones KB eds. *Obesity surgery: Principles and practice*. McGraw Hill, 2008: 55–60.
2. Stalzman E, Angerson W, *et al*. Criteria for patient selection and multidisciplinary evaluation and treatment of the weight loss surgery patient. *Obes Res* 2005: **13**: 234–43.
3. Markel TA, Mattar SG. Essentials of a bariatric program. In: Nguyen N, Hutter M, eds. *The Sages Manual: A practical guide to bariatric surgery*. Springer, 2008; 37–42.
4. Mattar SG, Rogula T. Essentials of a bariatric surgery program. In: Sugarman HJ, Nguyen N, eds. *Management of morbid obesity*. New York: Taylor & Francis, 2006; 61–73.
5. Schauer P, Ikramuddin S, Hamad G, Gourash W. The learning curve for laparoscopic Roux-en-Y gastric bypass is 100 cases. *Surg Endosc* 2003; **17**: 212–15.
6. Oliak D, Ballantyne P, Weber P, *et al*. Laparoscopic Roux-en-Y gastric bypass: defining the learning curve. *Surg Endosc* 2003; **17**: 405–8.
7. Bariatric Surgery Center of Excellence Requirements. American Society for Metabolic and Bariatric Surgery. 2008. http://www.surgicalreview.org/pcoe/tertiary/tertiary.aspx (Accessed 12/5/2008.)
8. Bariatric Surgery Center Network (BSCN) Accreditation Program. The American College of Surgeons. 2008. http://www.facs.org/cqi/bscn/index.html (Accessed 12/5/2008.)
9. American Society for Bariatric Surgery, Society for American Gastrointestinal Endoscopic Surgeons. Guidelines for laparoscopic and open surgical treatment of morbid obesity. *Obes Surg* 2000; **10**: 378–9.
10. Presutti, RJ, Gorman, RS, Swain, JM. Primary care perspective on bariatric surgery. *Mayo Clin Proc* 2004; **79**: 1158.
11. Bloomberg, RD, Fleishman, A, Nalle, JE, *et al*. Nutritional deficiencies following bariatric surgery: what have we learned? *Obes Surg* 2005; **15**: 145.
12. Pratt GM, McLees B, *et al*. The ASBS Bariatric Surgery Centers of Excellence Program: a blueprint for quality improvement. *Surg Obes Relat Dis* 2006: **2**: 497–503.
13. Betsy Lehman Center for Patient Safety and Medical Error Reduction Expert Panel on Weight Loss Surgery. Executive Report. Boston, MA: Commonwealth of Massachusetts. December 12, 2007.
14. Betsy Lehman Center for Patient Safety and Medical Error Reduction. Office of Health and Human Resources, Department of Public Health, Massachusetts. 2008. http://www.mass.gov/?pageID=eohhs2terminal&L=5&L0=Home&L1=Government&L2=Departments+and+Divisions&L3=Department+of+Public+Health&L4=Programs+and+Services+A+-+J&sid=Eeohhs2&b=terminalcontent&f=dph_patient_safety_g_betsy_overview&csid=Eeohhs2. (Accessed 12/5/2008.)
15. Jones DB, Walsh A, *et al*. A perioperative team approach to treating patients undergoing laparoscopic bariatric surgery. *AORN Journal* 2008; **88**: 59–64.

Chapter 24

Bariatric surgery in adolescents

Venita Chandra and Sanjeev Dutta

24.1 Introduction

Childhood and adolescent obesity are now considered independent risk factors for adult morbidity and premature mortality [1]. Bariatric surgery as a means to address this issue is an increasingly accepted concept, supported by growing data demonstrating positive impact on health outcomes. Adolescence represents a period of significant growth and maturation both physically and emotionally, thus issues unique to this patient population exist that must be addressed when considering bariatric surgery. This chapter focuses on aspects of bariatric surgery unique to the adolescent population including the health consequences of obesity in this age group, the indications for bariatric surgery, pre-operative and post-operative management, as well as a review of current outcomes.

24.2 Definition of obesity

In general, obesity is defined as an excess of body fat, although the exact definition of obesity in children and adolescents is subject to debate. Accurate assessment of body fat requires underwater weighing, dual energy x-ray absorptiometery, or bioelectric impedance, all of which are not practical for everyday use.

Body mass index (BMI, mass index, kg m^{-2}) is widely used as a surrogate measure of adiposity. An adult with a BMI ≥ 30 is considered obese. In children and adolescents who are still growing and have changing body shapes, BMI can be less accurate, particularly as it fails to distinguish between fat and fat-free mass. Thus, the application of growth charts and multiple percentiles is necessary to determine overweight and obesity for age and sex in this group [2]. Pediatric obesity is now defined by the Centers for Disease Control and Prevention as a BMI greater than the 95th percentile and overweight with a BMI greater than the 85th percentile. Exceeding the 99th percentile is referred to as extreme pediatric obesity [2].

24.3 Epidemiology

In the United States the proportion of children and adolescents who are obese has tripled over the past 30 years [3]. Recent prevalence studies in the US estimate the prevalence of overweight children and adolescents in the categories of ages 2–5, 6–11, and 12–19 are 13.9%, 18.8%, and 17.4%, respectively [4, 5]. Obesity rates are highest in Mexican Americans (31%), followed by non-Hispanic blacks (20%), non-Hispanic whites (15%), and Asian Americans (11%) [4, 6]. A study of over 3000 New York City elementary school students demonstrated that 43% of young children were overweight and more that half of these were obese, with significantly higher levels among Hispanics and Blacks. These trends are also reflected in developing countries worldwide. In China for example the prevalence of obesity in schoolchildren increased from 1.5% in the late 1980s to 12.6% in 1997 [8].

24.4 Risk factors

Overweight and obesity are complex multifactorial phenotypes influenced by an interaction of genetic, behavioral and environmental factors, and the overall risk accumulates with age.

There is robust data demonstrating an association between higher birth weight and higher attained BMI in childhood and early adulthood [9, 10]. Interestingly, lower birth weight has also been associated with increased risk of central obesity developing later [9], insulin resistance, and the metabolic syndrome [9, 11, 12]. Maternal obesity and gestational diabetes are strong predictors of childhood and adolescent obesity [10]. These risk factors have also been shown, when paired, to be associated with an increased risk of metabolic syndrome during childhood [10]. Parental obesity more than doubles the risk of adult obesity among both obese and non-obese

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

children under the age of ten [13]. Other variables that are shown to be risk factors include duration of breastfeeding, socioeconomic status, and maternal smoking status [14].

Ultimately the most important contributor to obesity is diet and lifestyle. Without question, sedentary children are at higher risk of becoming obese. Time spent watching television has been correlated to BMI, even more closely than time spent participating in vigorous activity [2]. Poor nutritional choices including skipping meals and resultant binge eating as well as increased fast food consumption have, unfortunately, become a common practice. By the age of 2 years, 12% of children consume more than 25% of calories from sodas and sugar-fortified juices [15], and fast food consumption now accounts for 10% of food ingestion by schoolchildren [2].

24.5 Health outcomes of adolescent obesity

Multiple studies suggest long-term health is significantly compromised due to persistence of adolescent overweight into adulthood [16, 17]. This manifests not only as an alarming increase in classically adult-type diseases in children, but also as harmful effects on their subsequent social and economic well-being.

24.5.1 Medical impact

As in adults, obesity in adolescents is associated with a large number of health consequences. Although these obesity-related co-morbidities occur more frequently in adults, significant consequences of obesity as well as the antecedents of adult disease occur in obese children and adolescents.

24.5.1.1 Metabolic syndrome and cardiac risk factors

The "metabolic syndrome" (MetS) is a cluster of risk factors that links insulin resistance, hypertension, dyslipidemia, type 2 diabetes and other metabolic abnormalities with an increased risk of later cardiovascular disease. (see Chapters 1 and 3) Cook and colleagues [18] studied the prevalence of MetS in a sample of adolescents from the third National Health and Nutrition Examination Survey (NHANES III), and found the syndrome present in 28.7% of overweight adolescents (BMI 95th percentile). More recent findings using modified criteria suggest that the MetS is far more common (nearly 50%) among overweight children and adolescents, and that its prevalence increases directly with the degree of obesity [19].

Obese children and adolescents have increased blood lipids, as well as glucose intolerance and diabetes. The incidence of diabetes among adolescents has increased 10-fold since 1982, and is felt to account for one third of all new cases of diabetes in children [20], these numbers being even higher in women and Hispanics. According to the National Health and Nutrition Examination Survey III type 2 diabetes mellitus affect 0.41% of all adolescents, more than double the prevalence of type 1 diabetes (0.17%) [21].

Hypertension is yet another example of a predominantly adult disease with a rising incidence in the pediatric population [22]. The long-term consequences are as yet unknown; however, there is some evidence that childhood hypertension can lead to adult hypertension, and thus the associated development of left ventricular hypertrophy, atherosclerosis and even early development of coronary artery disease [23].

24.5.1.2 Obstructive sleep apnea

Obstructive sleep apnea (OSA) is another significant health consequence of childhood obesity. Symptoms that may include snoring, poor school performance, enuresis and hyperactivity can have significant effects on quality of life. The prevalence of OSA in obese children and adolescents is quoted anywhere from 24 to 59%, and a direct correlation to BMI has been demonstrated [24, 25].

24.5.1.3 Pseudotumor cerebri

Pseudotumor cerebri is a rare disorder characterized by increased intracranial pressure. Symptoms include headache, visual field disturbances (the most severe is blindness), and often pulsatile tinnitus. Pseudotumor cerebri in adolescents has a direct correlation with obesity. Progressive visual impairment indicates the need for aggressive treatment of obesity in patients with this disease. Weight loss is associated with dramatic improvement in symptoms, and improvements in objective measures of the disease including visual field abnormalities and lumbar pressures [26, 27].

24.5.1.4 Musculoskeletal effects

Overweight children are susceptible to developing orthopedic complications because the tensile strength of bone and cartilage is not evolved to carry substantial quantities of excess weight. As a result, the excess weight carried by obese children is associated with bowing of long bones, which may cause injury to the growth plate and result in slipped capital femoral epiphysis, genu

Table 24.1 Consequences and co-morbidities of adolescent obesity

Psychosocial	Gastrointestinal
Low self esteem	Gallstones
Depression	Steatohepatitis
Eating disorders	Gastroesophageal reflux disease
Discrimination, prejudice, social marginalization	**Endocrine**
Poor quality of life, impairment of activities of daily living	Type 2 diabetes mellitus
Neurological	Insulin resistance
Pseudotumor cerebri	Metabolic syndrome
Pulmonary	Precocious puberty
Obstructive sleep apnea	Polycystic ovary syndrome
Asthma and exercise intolerance	**Musculoskeletal**
Cardiovascular	Slipped capital femoral epiphysis
Dyslipidemia	Blount's disease
Hypertension	Forearm fractures
Coagulopathy	Flat feet
Chronic inflammation	Osteoarthritis
Endothelial dysfunction	Scoliosis
Venous stasis disease	Spondylolisthesis
Renal	**Dermatologic**
Glomerulosclerosis	Intertriginous soft-tissue infections
	Acanthosis nigricans

valga, tibia vara (Blount's disease), scoliosis, osteoarthritis, and other injuries [28]. Both slipped capital femoral epiphysis and Blount's disease are pediatric orthopedic injuries that are highly associated with obesity in children, and prompt and sustained weight reduction is essential in their treatment.

24.6 Psychosocial impact

Obesity during some of the most psychosocially formative years of life can have significant impact on how children and adolescents adapt as effective members of society (Table 24.1). Obesity is one of the most stigmatizing and least socially acceptable conditions in childhood. Gortmaker and colleagues [29] looked at a cohort of 370 overweight adolescents and found that obese young women were less likely to marry, had lower incomes, and had completed less schooling than non-obese women, and that obese young men were less likely to marry than non-obese men. Health related quality of life (HRQoL) studies document marked impairments in all domains including physical functioning, emotional well-being, social relations, and school functioning in adolescents with severe obesity (BMI > 40 kg m^{-2}) [5]. This level of impairment is even worse than for those children and adolescents with chronic disease, or cancer.

Relative to average-weight peers, obese adolescents, particularly females, are socially marginalized and less likely to be nominated by their peers as a friend. Given the importance of peer acceptance, body image, and physical fitness to social and emotional development, being overweight may have lasting implications for child development and adolescent well-being. These adolescents are clearly at considerable risk of continued and mounting psychosocial impairment, and poor developmental adaptation. Among severely obese adolescents, there is a high incidence of low self-esteem, sadness, and moderate to severe depressive symptoms. Extreme obesity is associated with an increased risk of suicide and suicidal ideation among adolescents [28, 30]. The impact of this psychosocial impairment is grand, and some studies even suggest that obesity may be the worst socioeconomic handicap that women who were obese adolescents can suffer [23, 29].

24.7 Non-surgical therapies

The ideal treatment for obesity involves decreasing caloric intake while increasing caloric expenditure. Although no evidence-based overweight treatment guidelines exist for adolescent overweight, traditional clinical approaches include combinations of caloric restriction, exercise promotion, and behavior therapy. Considerable evidence shows that behavioral family-based treatment approaches are the most effective methods for the management of childhood obesity [31].

Experience with medication for use in adolescent weight loss is limited. Currently two medications, orlistat (Xenical®, Roche Pharmaceuticals, Nutley, NJ, USA) and sibutramine (Meridia®, Knoll Pharmaceutical Company, Bray, GA, USA) have received Food and Drug Administration approval for long-term use in adolescents. Orlistat inhibits pancreatic lipase and increases fecal losses of triglycerides. Although early evidence showed orlistat use to result in slight improvement in weight control [32], a more recent randomized controlled trial of adolescents using orlistat did not show significant reduction in BMI as compared to placebo at 6 months [33]. In addition, orlistat is associated with high study drop-out rates because of unacceptable flatulence and diarrhea as side effects of the drug. Sibutramine is a non-selective inhibitor of serotonin, norepinephrine, and dopamine, which acts as an anorectic by stimulating satiety. A randomized controlled trial showed a statistically significant amount of weight loss with sibutramine (10.3 kg +/−6.6 kg) plus diet and exercise as compared to placebo plus diet and exercise (2.4 +/−2.5 kg) [34]; however, the benefits appear to be only short term.

Successful weight loss and maintenance require great effort and commitment, and unfortunately have turned in generally unsatisfactory results. Although success is possible, most studies show that behavior modification and dieting are associated with poor weight loss, high attrition rates, and high probability of weight regain [28, 35]. For example, two recent trials followed obese pediatric patients for 1 year after initiation of non-surgical treatment, and found high drop-out rates (15–25%), and a 3.2 unit drop in BMI at best [36, 37].

24.8 Surgical therapies

Bariatric surgery appears to be the only intervention with evidence suggesting successful long-lasting (> 1 year) effects on body weight in severely obese adolescents. As a result, more and more pediatric providers are considering bariatric surgery for the treatment of obese adolescents. Accordingly, there has been a dramatic overall increase in recent years from approximately 13 000 operations in 1998 to approximately 121 000 operations in 2004 (these figures include adults) [36]. In addition, there has been a corresponding increase in pediatric bariatric surgery [38]. Evidence demonstrating the benefit of surgical weight loss in adults is extensive including not only dramatic reductions in BMI but resolution of associated co-morbidities, as well as reduced mortality [38–40]. Preliminary experience with bariatric surgery in adolescents suggests efficacy in ameliorating obesity-related morbidities as well [27, 41]. Thus, for severely obese adolescents who have failed organized attempts at achieving and maintaining weight loss through conventional non-operative approaches and who have serious or life-threatening conditions, bariatric surgery may provide the only practical alternative for achieving a healthy weight and for escaping the devastating physical and psychologic consequences of obesity [42].

24.9 Surgical options

The main bariatric surgical procedure used in the adolescent population today is Roux-en-Y gastric bypass (RYGB). Other bariatric surgical options include laparoscopic adjustable gastric banding (LAGB), vertical banded gastroplasty (VBG), biliopancreatic diversion, biliopancreatic diversion with duodenal switch (BPDS), banded bypass, and laparoscopic sleeve gastrectomy (LSG) [43]. Primarily malabsorptive procedures such as BPDS, which are occasionally used in adults, are not recommended for use in adolescents given their relative high rate of nutritional sequelae [44, 27]. No studies to date have compared efficacy and safety of various bariatric procedures among adolescents; however, both RYGB and adjustable gastric banding have been effective in treating the medical consequences of severe obesity in adolescence [27, 45, 46]. Laparoscopic sleeve gastrectomy is gaining wider acceptance as a viable option for adolescents that avoids the malabsorptive effects (and nutritional consequences) of gastric bypass, while achieving restrictive and hormonal (anti-ghrelin) effects. The operative details of these operations can be found elsewhere in this text. There are advantages and drawbacks to each of these procedures. While RYGB is well-documented to have beneficial effects on weight loss, its malabsorptive effects may potentially have long-term nutritional consequences for adolescents. Placing a foreign body such as a gastric band in an adolescent

avoids nutritional consequences and the risks associated with surgical anastomoses, but raises concerns of leaving a foreign body in place, potentially for many decades (erosion and need for replacement).

Laparoscopic adjustable gastric banding is not currently approved by the Food and Drug Administration in the United States for use in adolescents. Studies from Europe and Australia, where the technique has gained significant popularity show excellent outcomes in adults with lower complication rates as compared to RYGB, although preliminary US studies show mixed results [47, 48]. Some data suggest less total excess weight loss in LAGB patients as compared to RYGB, although this does not appear to affect resolution of comorbidities [49, 50]. In addition, current literature demonstrates similar effectiveness of LAGB in adolescents as for adults in terms of weight loss and resolution of co-morbidities [46, 51] including the most recent publication by Horgan and colleagues [46] reviewing four adolescents (age 17–19) who underwent the procedure.

Laparoscopic sleeve gastrectomy consists of a laparoscopic partial gastrectomy in which a tubular stomach is created by removing the majority of the greater curvature. This restrictive procedure reduces the capacity of the stomach, such that it resists stretching due to the absence of fundus and is devoid of ghrelin-producing cells (a gut hormone involved in regulating food intake). Experience in the adult population suggests that it is a safe, beneficial and effective approach both as a short-term solution prior to RYGB as well as a stand-alone technique [43, 52]. The obvious advantages of LSG are effective weight loss without a foreign body and without a lifelong dissociation of the gastrointestinal tract. A recently published case series of four children/adolescents (average age 14.5), demonstrated that at a 1-year follow-up, LSG proved a safe and effective option for bariatric surgery in children, achieving moderate weight loss (decrease in BMI of 11 units) and improvement of co-morbidities [52].

24.10 Guidelines for bariatric surgery in adolescents

In 1991, the National Institutes of Health published consensus guidelines for bariatric surgery in adults. Based on these recommendations bariatric surgery is commonly performed in adults with BMI values of 35 kg m^{-2} with co-morbidities and for BMI values of 40 kg m^{-2} with or without co-morbidities. However, simple adoption of these guidelines for use in younger age groups was generally not felt to be appropriate, at least in the early experimental stages [53].

Recommendations specific for bariatric surgery in adolescents were therefore developed by a panel of experts in the field of pediatric obesity [42]. Given the unique metabolic, developmental and psychologic needs of adolescents, bariatric surgery in this population should only be performed at specialized centers under the supervision of multidisciplinary teams of experts experienced in meeting these distinct needs. These teams should include specialists in adolescent obesity evaluation and management, psychology, nutrition, physical activity instruction, and bariatric surgery [42]. Depending on the needs of the individual patients, other pediatric experts in fields such as gynecology, endocrinology, pulmonology, gastroenterology, cardiology, anesthesiology, or orthopedics may be utilized.

It is imperative that pediatric surgical specialists performing minimally invasive bariatric procedures have specialized training. There is substantial data showing that minimally invasive bariatric surgery is one of the more technically difficult operations to perform, with a steep learning curve and demonstrated differences in outcome depending on training background of the surgeons [54]. Pediatric surgeons involved in bariatric surgery should pursue advanced training and credentialing as recommended by the American Society for Metabolic Bariatric Surgery. In addition, their early experience should be done as a partnership with an experienced bariatric surgical specialist.

Adolescents who have failed multiple non-surgical weight loss attempts may be considered candidates for surgical intervention. Table 24.2 lists the criteria recommended by Inge and colleagues [42] for patients being considered for bariatric surgery. In general, bariatric surgery is considered an appropriate option for those adolescents with very severe obesity (BMI ≥ 40 kg m^{-2}) along with the presence of serious co-morbidities, as well as for patients with higher BMI values (≥ 50 kg m^{-2}) with associated less serious obesity-related co-morbid conditions [42] (Table 24.2). More recently, there has been a call to liberalize indications for surgery in adolescents to match those prescribed for adults [55]. Contraindications to surgery include medically correctable causes of obesity, recent substance abuse problems, concern for adherence to post-operative recommendations, current lactation or pregnancy, or planned pregnancy within 2 years after surgery (Table 24.3).

Table 24.2 Criteria for adolescent bariatric surgery

Failure of ≥ 6 months of organized weight loss attempts
Attainment of physiologic maturity
BMI ≥ 40 with serious obesity-related co-morbidities [a]
BMI ≥ 50 with less serious obesity-related co-morbidities [b]
Commitment to comprehensive medical and psychologic evaluations before and after surgery
Commitment to medical and nutritional requirements post-operatively
Ability to provide informed assent for surgical treatment
Demonstrate cognitive maturity and decisional capacity
Supportive family environment

[a] Serious co-morbidities: Type 2 diabetes mellitus, obstructive sleep apnea, or pseudotumor cerebri.
[b] Less serious co-morbidities: hypertension, dylipidemias, non-alcoholic steatohepatitis, venous stasis disease, significant impairment in activities of daily living, intertriginous soft-tissue infections, stress urinary incontinence, gastroesophageal reflux disease, weight related arthropathies that impair physical activity, psychosocial distress.

Table 24.3 Contraindications to adolescent bariatric surgery

Medically correctable cause of obesity
Substance abuse problem within preceding year
Medical, psychiatric or cognitive condition that would impair the patient's ability to adhere to dietary or medication regimen
Current lactation
Current pregnancy or planned pregnancy within 2 years after surgery
Inability to comprehend or refusal to participate in lifelong medical surveillance

24.11 Pre-operative evaluation

Intensive patient and family pre-operative education and evaluation is imperative for the success of bariatric surgery programs. Medical evaluations should include investigation into possible endogenous causes of obesity that may be amenable to treatment as well as identification of any obesity-related health complications, as is done in the adult population. Pre-operative evaluation at our institution Lucille Salter Packard Children's Hospital at Stanford involves some or all of the procedures listed below as indicated for each individual patient

- A consistent primary care provider (≥1 year relationship)
- Evaluation by pediatric weight clinic
- Evaluation by dietician
- Evaluation by psychiatrist
- Evaluation by physical therapist
- Completion of a detailed health questionnaire
- Electrocardiogram (ECG)
- Echocardiogram (ECHO)
- Ultrasound (to assess for steatohepatitis and cholelithiasis)
- Patients with symptomatic gallstones should have a cholecystectomy before the bariatric procedure.
- Bone age study (when indicated)
- Polysomnography (sleep study)
- Pulmonary function test and/or indirect calorimetry
- Endoscopy
- Attendance of support groups and education session.
- Blood tests
  - Complete blood count
  - Serum electrolytes, renal and liver function tests
  - Calcium and phosphate levels, uric acid
  - Fasting lipids
  - Insulin, blood sugar, hemoglobin A1C
  - Thyroid function tests
  - Blood coagulation studies (prothrombin time, partial thromboplastin time, and international normalized ratio)

Physiologic maturity must be established prior to consideration of bariatric surgery, as the dietary complexities and potential nutritional consequences following surgery can stunt completion of growth. Physiologic maturation usually occurs along with sexual maturation (Tanner) stage 3 or 4. Most often skeletal maturation (> 95% of adult stature) is attained by age 14 in girls and 16 in boys. Obesity is usually associated with precocious puberty, and thus overweight children are often taller and have advanced bone age compared with age-matched non-overweight children. If there is uncertainty about whether adult stature has been attained, however, skeletal maturation (bone age) can be assessed objectively using a radiograph of the hand and wrist.

In addition to undergoing medical assessment, comprehensive psychologic evaluations of both potential candidates for bariatric surgery and their parents should be performed [42]. This involves assessment of the family unit, determination of coping skills, assessment of

the severity of psychosocial co-morbidities, review of past/present psychiatric, emotional, behavioral or eating disorders, and evaluation of cognitive development, including determination of decisional capacity.

These evaluations serve to define potential supports and barriers to patient adherence as well as patient and family preparedness for surgery and the required post-operative lifestyle changes. An in-depth understanding, by the team, of the patients' psychologic makeup and their family strengths or family dysfunction could have significant effects on the overall success of bariatric surgery. In addition although consent for the surgical intervention must be obtained from the parents, ethically, the decisional capacity of the adolescent and their ability to give assent for surgery are of utmost importance, and need to be clarified prior to proceeding with bariatric surgery.

24.12 Post-operative management

Post-operative follow up is generally quite intensive in order to verify adherence to diet and vitamin guidelines, ensure optimal post-operative weight loss, and avoid nutritional complications. Often programs establish follow-up visits in the following manner: weekly for 1 month, monthly until 6 months, quarterly until first 12 months, biannually until 24 months, and yearly thereafter [56]. It is strongly encouraged that all patients have lifelong follow-up in order to ensure optimal weight maintenance, and overall health. In addition, the long-term effects of bariatric surgery in this patient population are still unknown, thus ongoing rigorous clinical data collection will allow for structured clinical trials and observations to assist in our understanding and improve patient care.

24.13 Nutritional consequences

Both gastric restrictive and bypass procedures carry an associated risk of macronutrient as well as micronutrient deficiency. In adolescents, the long-term risk of mineral or micronutrient deficiency, though not well defined, is a legitimate concern. Vitamin and mineral deficiencies including hypovitaminosis A, B_{12}, C, D, E, folic acid, and iron have all been reported [57]. The presumed mechanism for these deficiencies is thought to be malabsorption along with decreased oral intake, including poor compliance with medications post-operatively. Vitamin and mineral supplementation is required in order to optimize bone growth in growing adolescents and to avoid nutritional consequences discussed more in detail below. This usually includes chewable or soluble multivitamins, calcium citrate (1200–1500 mg day^{-1}) as well as B-complex supplements to reduce the risk of beriberi, which has been documented in adolescents after gastric bypass surgery [58].

Menstruating females should also take iron supplements. Given the exponential skeletal growth that occurs during adolescence, it is unclear whether or not the current recommended amount of calcium supplements will be adequate to optimize bone growth. The decrease in bone density that occurs after surgical weight loss, combined with potential vitamin D and calcium deficiencies may put adolescent bariatric patients at greater risk for fractures later in life.

24.14 Compliance

Adolescence is often regarded as a period of experimentation, rebellion, risk taking, and egocentrism. All of these make surgical preparation and adolescent compliance to recommended health behaviors uniquely challenging, particularly when pursuing life-altering procedures like bariatric surgery. Compliance with healthcare recommendations in adolescents is shown to be disappointingly low. Adolescents with chronic medical conditions such as cystic fibrosis, cancer, diabetes and asthma have compliance rates of approximately 40–50% [59]. Rand and colleagues [45] reported poor compliance by adolescents following gastric bypass surgery, with less than 15% of adolescents demonstrating compliance to post-operative dietary multivitamin and nutrient supplementation.

Noncompliance is often associated with such psychosocial factors as low self-esteem, poor cognitive abilities, and insufficient family support. Several studies suggest behavioral therapy can improve adolescent adherence to strict medical and dietary regimens [60]. Continued support by behavioral psychologists with expertise in enhancing adherence is essential for success in dietary compliance and long-term follow-up after bariatric procedures in adolescents. With the alterations in eating patterns that are required after bariatric surgery, repetitive reinforcement with structured family involvement and continued support is needed to facilitate the formation of lifelong health-promoting habits.

Adolescent females that undergo bariatric surgery may engage in more sexually promiscuous behavior after weight loss. Surgery does not appear to affect the outcome of subsequent pregnancies as long as the period of rapid weight loss has passed, thus pregnancy

is contraindicated for 2 years after surgery [61]. At our institution, patients are required to commit to pregnancy avoidance during this period of time as part of their preoperative workup.].

24.15 Outcomes

There is currently a paucity of long-term outcomes literature of bariatric surgery in adolescents. The majority of recent studies do, however, demonstrate the safety and efficacy of bariatric surgery in the adolescent patient in achieving durable weight loss, and amelioration of obesity-related co-morbidities [42, 49, 51, 62–64].

In the largest long-term series to date, Sugerman and colleagues [27] reviewed 20 years' experience with Roux-en-Y gastric bypass surgery in adolescents (the majority were open procedures) They demonstrated results similar to adult patients, including sustained weight loss, correction of co-morbidities, and improved self-image. Surgery was followed by continued weight loss in 84.8% of subjects with a mean excess weight loss of 63%. Long-term follow up also showed a general resolution of co-morbidities as well as an elevation in self-esteem and socializing [27]. More recent experience with laparoscopic RYGB also demonstrates excellent excess weight loss, and resolution of co-morbidities, although long-term data is still pending [63, 64].

Perhaps even more reassuring than the amount of excess weight loss is the dramatic improvement in most obesity-related co-morbidities that are being demonstrated after bariatric surgery. These have been very clearly demonstrated in adults, and early reports in adolescents are also showing this to be true [26, 27, 65]. Lawson and colleagues [63] recently published the first outcomes report from the Pediatric Bariatric Study Group, with their retrospective review of 39 MO adolescents who underwent RYGB and 12 who were treated non-surgically. In addition to a mean reduction in BMI of 37% in surgical patients (compared to 3% in non-surgical patients), they demonstrated significant improvements in triglycerides, total cholesterol, fasting blood glucose, and fasting insulin after one year. Rand and colleagues [45] reported excellent psychosocial adjustment 6 years after bariatric surgery with patients reporting increased self-esteem, improved social relationships, and feeling more attractive.

Late weight gain remains a potential concern, and is still unclear given the limited long-term data. Recidivism in the form of weight gain is estimated at 20–30% in adults. Durable weight loss occurs in most adolescents, yet up to 15% of these patients appear to have late weight regain [65]. This occurrence may be avoided with a behavioral management program specifically designed for the adolescent [31]. More long-term studies are necessary to further clarify this risk.

Adjustable gastric banding also appears to demonstrate efficacy at least in terms of short-term weight loss efficacy in adolescents. A recent study by Nadler *et al.* [66] of 73 adolescents who underwent LAGB demonstrated a mean excess weight loss of more than 55% at both 1- and 2-year follow-up with minimal morbidity, and excellent resolution or improvement of co-morbid conditions. Although generally considered a safer procedure, with less morbidity than RYGB, BMI reduction appears to be larger after RYGB [36]. Regardless, LAGB is as still a relatively novel procedure, and the long-term efficacy and consequences remain unknown.

Many questions in terms of outcomes of adolescent bariatric surgery remain to be answered. The Teen Longitudinal Assessment of Bariatric Surgery (Teen-LABS), an ongoing four-center study devoted to prospective examination of the outcomes of pediatric bariatric surgery, may answer many of these outstanding questions [67]. The plan is to enroll 200 patients, all aged 19 or less, and examine outcomes after bariatric surgery (see http://www.cincinnatichildrens.org/teen-LABS for details). Researchers will not only collect and analyze data in adolescents, but they will also compare these results to surgical outcomes in 200 adults who had a history of severe obesity before the age of 18 but did not receive surgery at that time. This comparison may shed light on the health implications of postponing surgery.

24.16 Summary

Adolescent obesity is quickly becoming a worldwide epidemic. The impact of its attendant co-morbidities will undoubtedly prove devastating to the health of populations across the globe unless practical solutions can be achieved. Programs aimed at prevention clearly must form the cornerstone of this effort. However, effective treatment for those adolescents already suffering from obesity cannot be delayed. There is substantial evidence supporting the benefits of bariatric surgery in this group in terms of excess weight loss and resolution of co-morbidities. The development of multidisciplinary adolescent bariatric teams, both at individual hospitals and on a national and international level, will aid in further clarifying the best treatment strategies.

References

1. Freedman DS, Khan LK, Dietz WH, *et al*. Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics* 2001; **108**: 712.
2. Sinha A, Kling S. A review of adolescent obesity: prevalence, etiology, and treatment. *Obes Surg* 2009; **19**: 113–20.
3. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA* 2002; **288**: 1728.
4. Ogden CL, Carroll MD, Curtin LR, *et al*. Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006; **295**: 1549.
5. Modi AC, Loux TJ, Bell SK, *et al*. Weight-specific health-related quality of life in adolescents with extreme obesity. *Obesity* 2008; **16**: 2266–71.
6. Freedman DS, Khan LK, Serdula MK, *et al*. Racial and ethnic differences in secular trends for childhood BMI, weight, and height. *Obesity* 2006; **14**: 301.
7. Thorpe LE, List DG, Marx T, *et al*. Childhood obesity in New York City elementary school students. *Am J Public Health* 2004; **94**: 1496.
8. Luo J, Hu FB. Time trends of obesity in pre-school children in China from 1989 to 1997. *Int J Obes* 2002; **26**: 553.
9. Oken E, Gillman MW. Fetal origins of obesity. *Obes Res* 2003; **11**: 496.
10. Boney CM, Verma A, Tucker R, Vohr BR. Metabolic syndrome in childhood: association with birth weight, maternal obesity, and gestational diabetes mellitus. *Pediatrics* 2005; **115**: 290.
11. Barker M, Robinson S, Osmond C, Barker DJ. Birth weight and body fat distribution in adolescent girls. *Arch Dise Child* 1997; **77**: 381.
12. Poulsen P, Vaag A. The intrauterine environment as reflected by birth size and twin and zygosity status influences insulin action and intracellular glucose metabolism in an age- or time-dependent manner. *Diabetes* 2006; **55**: 1819.
13. Whitaker RC, Wright JA, Pepe MS, *et al*. Predicting obesity in young adulthood from childhood and parental obesity. *N Engl J Med* 1997; **337**: 869.
14. Burke V, Beilin LJ, Simmer K, *et al*. Predictors of body mass index and associations with cardiovascular risk factors in Australian children: a prospective cohort study. *Int J Obes* 2005; **29**: 15.
15. Kranz S, Smiciklas-Wright H, Siega-Riz AM, Mitchell D. Adverse effect of high added sugar consumption on dietary intake in American preschoolers. *J Pediatr* 2005; **146**: 105–11.
16. Freedman DS, Shear CL, Burke GL, *et al*. Persistence of juvenile-onset obesity over eight years: the Bogalusa Heart Study. *Am J Public Health* 1987; **77**: 588.
17. Must A, Jacques PF, Dallal GE, *et al*. Long-term morbidity and mortality of overweight adolescents. A follow-up of the Harvard Growth Study of 1922 to 1935. *N Engl J Med* 1992; **327**: 1350.
18. Cook S, Weitzman M, Auinger P, *et al*. Prevalence of a metabolic syndrome phenotype in adolescents: findings from the third National Health and Nutrition Examination Survey, 1988–1994. *Arch Pediatr Adolesc Med* 2003; **157**: 821.
19. Weiss R, Dziura J, Burgert TS, *et al*. Obesity and the metabolic syndrome in children and adolescents. *N Engl J Med* 2004; **350**: 2362.
20. Pinhas-Hamiel O, Dolan LM, Daniels SR, *et al*. Increased incidence of non-insulin-dependent diabetes mellitus among adolescents. *J Pediatr* 1996; **128**: 608.
21. Daniels SR, Arnett DK, Eckel RH, *et al*. Overweight in children and adolescents: pathophysiology, consequences, prevention, and treatment. *Circulation* 2005; **111**: 1999–2012.
22. Sorof JM, Lai D, Turner J, *et al*. Overweight, ethnicity, and the prevalence of hypertension in school-aged children. *Pediatrics* 2004; **113**: 475.
23. Dietz WH. Health consequences of obesity in youth: childhood predictors of adult disease. *Pediatrics* 1998; **101**: 518.
24. Mallory GB, Fiser DH, Jackson R. Sleep-associated breathing disorders in morbidly obese children and adolescents. *J Pediatr* 1989; **115**: 892.
25. Kalra M, Inge T, Garcia V, *et al*. Obstructive sleep apnea in extremely overweight adolescents undergoing bariatric surgery. *Obes Research* 2005; **13**: 1175.
26. Chandra V, Dutta S, Albanese CT, *et al*. Clinical resolution of severely symptomatic pseudotumor cerebri after gastric bypass in an adolescent. *Surg Obes Rel Dis* 2007; **3**: 198–200.
27. Sugerman HJ, Sugerman EL, DeMaria EJ, *et al*. Bariatric surgery for severely obese adolescents. *J Gastrointest Surg* 2003; **7**: 102.
28. Helmrath MA, Brandt ML, Inge TH. Adolescent obesity and bariatric surgery. *Surg Clin North Am* 2006; **86**: 441.
29. Gortmaker SL, Must A, Perrin JM, *et al*. Social and economic consequences of overweight in adolescence and young adulthood. *N Engl J Med* 1993; **329**: 1008.
30. Eisenberg ME, Neumark-Sztainer D, Story M. Associations of weight-based teasing and emotional well-being among adolescents. *Arch Pediatr Adolesc Med* 2003; **157**: 733.
31. Epstein LH, Myers MD, Raynor HA, Saelens BE. Treatment of pediatric obesity. *Pediatrics* 1998; **101**: 554.

32. Chanoine J-P, Hampl S, Jensen C, *et al*. Effect of orlistat on weight and body composition in obese adolescents: a randomized controlled trial. *JAMA* 2005; **293**: 2873.
33. Maahs D, de Serna DG, Kolotkin RL, *et al*. Randomized, double-blind, placebo-controlled trial of orlistat for weight loss in adolescents. *Endocr Pract* 2006; **12**: 18.
34. Godoy-Matos A, Carraro L, Vieira A, *et al*. Treatment of obese adolescents with sibutramine: a randomized, double-blind, controlled study. *J Clin Endocrinol Metabol* 2005; **90**: 1460.
35. Methods for voluntary weight loss and control. NIH Technology Assessment Conference Panel. Consensus Development Conference, 30 March to 1 April 1992. *Ann Intern Med* 1993; **119**: 764.
36. Treadwell JR, Sun F, Schoelles K. Systematic review and meta-analysis of bariatric surgery for pediatric obesity. *Ann Surg* 2008; **248**: 763–76.
37. Savoye M, Shaw M, Dziura J, *et al*. Effects of a weight management program on body composition and metabolic parameters in overweight children: a randomized controlled trial. *JAMA* 2007; **297**: 2697–704.
38. Schilling PL, Davis MM, *et al*. National trends in adolescent bariatric surgical procedures and implications for surgical centers of excellence. *J Am Coll Surg* 2008; **206**: 1–12.
39. Flum DR, Dellinger EP. Impact of gastric bypass operation on survival: a population-based analysis. *J Am Coll Surg* 2004; **199**: 543.
40. Christou NV, Sampalis JS, Liberman M, *et al*. Surgery decreases long-term mortality, morbidity, and health care use in morbidly obese patients. *Ann Surg* 2004; **240**: 416.
41. Strauss RS, Bradley LJ, Brolin RE. Gastric bypass surgery in adolescents with morbid obesity. *J Pediatr* 2001; **138**: 499.
42. Inge TH, Krebs NF, Garcia VF, *et al*. Bariatric surgery for severely overweight adolescents: concerns and recommendations. *Pediatrics* 2004; **114**: 217.
43. Till HKH, Muensterer O, Keller A, *et al*. Laparoscopic sleeve gastrectomy achieves substantial weight loss in an adolescent girl with morbid obesity. *Eur J Pediatr Surg* 2008; **18**: 47–9.
44. Nadler EP, Kane TD. Bariatric Surgery. In: Langer JC, Albanese CT, eds. *Pediatric Minimal Access Surgery*. Boca Raton: Taylor & Francis, 2005, pp. 319–330.
45. Rand CS, Macgregor AM. Adolescents having obesity surgery: a 6-year follow-up. *South Med J* 1994; **87**: 1208.
46. Horgan S, Holterman MJ, Jacobsen GR, *et al*. Laparoscopic adjustable gastric banding for the treatment of adolescent morbid obesity in the United States: a safe alternative to gastric bypass. *J Pediatr Surg* 2005; **40**: 86.
47. O 'Brien PE, Dixon JB, Laurie C, *et al*. Treatment of mild to moderate obesity with laparoscopic adjustable gastric banding or an intensive medical program: a randomized trial. *Ann Int Med* 2006; **144**: 625.
48. Weiner R, Blanco-Engert R, Weiner S, *et al*. Outcome after laparoscopic adjustable gastric banding – 8 years experience. *Obes Surg* 2003; **13**: 427.
49. Angrisani L, Furbetta F, Doldi SB, *et al*. Results of the Italian multicenter study on 239 super-obese patients treated by adjustable gastric banding. *Obes Surg* 2002; **12**: 846.
50. Mognol P, Chosidow D, Marmuse J-P. Laparoscopic gastric bypass versus laparoscopic adjustable gastric banding in the super-obese: a comparative study of 290 patients. *Obes Surg* 2005; **15**: 76.
51. Abu-Abeid S, Gavert N, Klausner JM, Szold A. Bariatric surgery in adolescence. *J Pediatr Surg* 2003; **38**: 1379.
52. Till H, Blüher S, Hirsch W, Kiess W. Efficacy of laparoscopic sleeve gastrectomy (LSG) as a stand-alone technique for children with morbid obesity. *Obes Surg* 2008; **18**: 1047–9.
53. Gastrointestinal surgery for severe obesity. Proceedings of National Institutes of Health Consensus Development Conference. March 25–27, 1991, Bethesda, MD. The *Am J Clin Nutr* 1992; **55**(2 Suppl): 487S.
54. Hsu GP, Morton JM, Jin L, *et al*. Laparoscopic Roux-en-Y gastric bypass: differences in outcome between attendings and assistants of different training backgrounds. *Obes Surg* 2005; **15**: 1104.
55. Inge TH, Xanthakos SA, Zeller MH. Bariatric surgery for pediatric extreme obesity: now or later? *Int J Obes* 2007; **31**: 1–14.
56. Inge TH, Zeller M, Garcia VF, Daniels SR. Surgical approach to adolescent obesity. *Adolesc Med Clin* 2004; **15**: 429.
57. Halverson JD. Vitamin and mineral deficiencies following obesity surgery. *Gastroenterol Clin North Am* 1987; **16**: 307.
58. Towbin A, Inge TH, Garcia VF, *et al*. Beriberi after gastric bypass surgery in adolescence. *J Pediatr* 2004; **145**: 263.
59. Inge TH, Garcia V, Daniels S, *et al*. A multidisciplinary approach to the adolescent bariatric surgical patient. *J Pediatr Surg* 2004; **39**: 442.
60. Lemanek KL, Kamps J, Chung NB. Empirically supported treatments in pediatric psychology: regimen adherence. *J Pediatr Psychol* 2001; **26**: 253.
61. Sheiner E, Levy A, Silverberg D, *et al*. Pregnancy after bariatric surgery is not associated with adverse perinatal outcome. *Am J Obstetr Gynecol* 2004; **190**: 1335.
62. Inge TH, Zeller MH, Lawson ML, Daniels SR. A critical appraisal of evidence supporting a bariatric surgical

approach to weight management for adolescents. *J Pediatr* 2005; **147**: 10.

63. Lawson ML, Kirk S, Mitchell T, *et al*. One-year outcomes of Roux-en-Y gastric bypass for morbidly obese adolescents: a multicenter study from the Pediatric Bariatric Study Group. *J Pediatr Surg* 2006; **41**: 137.
64. Stanford A, Glascock JM, Eid GM, *et al*. Laparoscopic Roux-en-Y gastric bypass in morbidly obese adolescents. *J Pediatr Surg* 2003; **38**: 430.
65. Sugerman HJ, Fairman RP, Sood RK, *et al*. Long-term effects of gastric surgery for treating respiratory insufficiency of obesity. *Am J Clin Nutr* 1992; **55** (2 Suppl): 597S.
66. Nadler EP, Youn HA, Ren CJ, Fielding GA. An update on 73 US obese pediatric patients treated with laparoscopic adjustable gastric banding: comorbidity resolution and compliance data. *J Pediatr Surg* 2008; **43**: 141–6.
67. Inge TH, Zeller M, Harmon C, *et al*. Teen-Longitudinal Assessment of Bariatric Surgery: methodological features of the first prospective multicenter study of adolescent bariatric surgery. *J Pediatr Surg* 2007; **42**: 1969–71.

Chapter 25

Management of the obese parturient

Yigal Leykin

25.1 Introduction

The prevalence of significant obesity continues to rise in both developed and developing countries. Consequently, the obesity epidemic also involves females of reproductive age [1]. Maternal obesity is associated with many complications during pregnancy, especially gestational diabetes and hypertensive disorders of pregnancy. Maternal obesity is also associated with fetal complications, like macrosomia, stillbirth, and early neonatal death [2, 3]. Maternal obesity also increases long-term risks for the fetus. Children born to obese mothers are twice as likely to be obese themselves and to develop type 2 diabetes later in life [4, 5]. Obstetric delivery in obese women is characterized by a high Cesarean-section rate and an increased risk of anesthetic and post-operative complications [6]. Both obesity, and excessive maternal weight gain during pregnancy contribute to increased difficulties and risks of general and regional anesthesia techniques [7].

25.2 Epidemiology

According to data collected for the National Health and Nutrition Examination Survey, among American women ages 20–39 years obesity rates increased from 21% to 28% between 1999 and 2000 [8]. In nine US states the prevalence of pre-pregnancy obesity among women who delivered live infants was 13% in 1993/94 and 22% in 2002/2003, with a mean increase of 69.3%, and an increase of 45% to 105% for individual states [9]. In England the percentage of women of reproductive age with BMI > 30 kg m^{-2} increased from 12% in 1993 to 18% in 2002 [10]. In Brazil the prevalence was less, about 5.5% of parturients are obese [11, 12]. In a study on 14 230 Australian pregnant women, 34% were overweight, obese or MO [13, 14].

The 2007 report of the Confidential Enquiry Into Maternal and Child Health in the United Kingdom concluded that 27% of maternal deaths during the period 2003–2005 occurred in obese women (BMI > 30 kg m^{-2}), and an additional 24% of maternal deaths occurred among overweight women (BMI > 25 kg m^{-2}) [15].

Adolescent pregnancy is a significant public health focus. Overweight adolescent women are also at increased risk for adverse neonatal and peri-natal outcomes. The World Health Organization reports that approximately 17 million adolescent girls (60 births/1000 girls) give birth each year. In the 1960s and 1970s the prevalence of overweight was 4.7% among girls ages 12–19 years old, compared with a prevalence of 15.0% in the 1999 to 2002 survey [16].

25.3 Physiologic changes

Normally, gestation is coupled with significant physiologic changes. The association between obesity and pregnancy can result in further limitation of parturient physiologic reserve. The presence of obesity comorbidities may represent an additional risk for pregnancy outcome.

25.3.1 Cardiovascular system

In the pregnant woman, cardiovascular changes due to an increase in oxygen demand include increased cardiac output and blood volume expansion coupled with reduced systemic vascular resistance (Table 25.1). During labour, cardiac output increases further and the immediate post-partum uterine contractions are responsible for additional increases, with a peak cardiac output of as much as 75% above pre-delivery values [17].

Excess weight also results in a rise of cardiac output. Stroke volume increases in obese patients since a greater total blood volume is needed to perfuse the added lean tissue and body fat. Increased cardiac output combined

Morbid Obesity: Peri-operative Management, Second Edition, ed. Adrian Alvarez, Jay B. Brodsky, Hendrikus J. M. Lemmens and John M. Morton. Published by Cambridge University Press.

Table 25.1 Effects of obesity, pregnancy and combined obesity/pregnancy on the cardio-respiratory systems

Parameter	Pregnancy	Obesity	Combined
Heart rate	Increase +	Increase ++	Increase ++
Stroke volume	Increase ++	Increase +	Increase +
Cardiac output	Increase ++	Increase ++	Increase +++
Systemic vascular resistance	Decrease ++	Increase ++	No change or decrease +
Mean arterial pressure	Increase +	Increase ++	Increase ++
Central venous pressure	No change	Increase +	Increase ++
Pulmonary hypertension	absent	May be present	May be present
Respiratory rate	Increase +	No change or increase +	Increase +
Tidal volume	Increase +	Decrease +	Increase +
Minute volume	Increase +	No change or decrease +	Increase +
Inspiratory capacity	Increase +	Decrease +	Increase +
Inspiratory reserve volume	Increase +	Decrease +	Increase +
Expiratory reserve volume	Decrease +	Decrease ++	Decrease +
Residual volume	Decrease +	No change or decrease +	Increase +
Functional residual capacity	Decrease ++	Decrease +++	Decrease ++
Vital capacity	No change	Decrease +	Decrease +
Total lung capacity	Decrease +	Decrease ++	Decrease +
PaO_2	Decrease +	Decrease ++	Decrease +
$PaCO_2$	Decrease +	Increase +	Decrease +

Notes: PaO_2, partial presure of oxygen; $paCO_2$, partial pressure of carbon dioxide.

with normal peripheral vascular resistance may lead to systemic hypertension. Mild to moderate hypertension is seen in most MO patients. The increased left ventricular wall stress caused by increased stroke volume and the resultant ventricular dilation may lead to cardiac hypertrophy. However, the extent of cardiovascular pathologic changes secondary to obesity is dependent on the duration of obesity and its severity.

In the moderately overweight parturient, the incidence of hypertension and toxemic syndromes is 2.0–3.7 and 1.5–1.9 times higher, respectively, than in control subjects. In obese women, the incidence of hypertension is multiplied by a factor estimated to range from 2.2 to 21.0 and that of toxemia by 1.2 to 9.7. Obese women have a two-to five-fold higher incidence of pre-eclampsia (hypertension with proteinuria) during pregnancy [18].

Aorto-caval compression by the enlarged uterus with the parturient in the supine position during the second half of pregnancy may lead to hypotension which can compromise utero-placental blood flow and place the patient at increased risk of cardiovascular collapse [19]. This syndrome is greatly exacerbated in the obese patient, because their large panniculus may further compress the great vessels. Two cases of sudden death in non-pregnant MO patients have been attributed to supine position and consequent circulatory changes [20].

25.3.2 Respiratory system

During pregnancy, progesterone stimulation of the respiratory center in the brainstem and relaxation of the airway smooth muscle with consequent decrease of airway resistance, results in reduction of some negative effects of obesity on the respiratory system [21] (Table 25.1).

In obese patients functional residual capacity (FRC) is significantly reduced due to a decrease in expiratory reserve volume (ERV). However, FRC in the obese pregnant patient decreases less than the FRC of a normal weight pregnant patient [22]. The supine and especially the Trendelenburg position considerably worsen lung volumes of the obese parturient. Arterial blood gas analysis demonstrates much more frequent oxygen desaturation in the obese parturient compared to the non-obese parturient, stressing the importance of adequate pre-oxygenation before induction of general anesthesia [22].

The ventilatory stimulating effect of progesterone and, in the later part of pregnancy, the tendency to sleep on the side can offer some protective effect on

obstructive sleep apnea [23]. Obstructive sleep apnea is not uncommon in the obese parturient, and these patients are at increased risk of systemic and pulmonary hypertension, coronary artery disease, cardiac arrhythmias, and oxygen desaturation, which can result in fetal hypoxia and poor fetal growth [24].

25.3.3 Other systems

Anemia appears to occur less often in severely obese pregnant women than in normal weight ones [25].

The gastric volume in the obese parturient is five times greater than in non-obese parturients, and therefore the risk of regurgitation and aspiration is significantly increased [7, 26].

Obesity further increases the risk of glucose intolerance and insulin resistance, while the incidence of gestational diabetes mellitus in a parturient with a BMI > 30 kg m^{-2} or total body weight (TBW) > 150% of ideal body weight is 1.4 to 20-fold higher than in normal weight subjects [11, 27].

25.4 Complications

Obese women have a higher risk of obstetric complications, which may involve both the mother and infant (Table 25.2) Obesity has been also identified as a significant risk factor for anesthesia-related maternal mortality [15]. Even in moderately overweight mothers (BMI 25–30 kg m^{-2} or 120–150% of ideal body weight) the incidence of perinatal infant death was 1.15–2.5 fold higher than in normal weight women [28, 29].

The associations between obesity and hypertensive disorders of pregnancy, diabetes and delivery by cesarean section are well documented [7]. The rate of cesarean deliveries in obese women is 1.15–3.0 fold higher compared to normal weight patients [11]. Obesity is an intrinsic risk factor for both increased surgical blood loss and post-partum hemorrhage [30].

In the obese parturient there is a higher risk of other delivery and post-partum complications. An increased risk of venous thromboembolic events has been also demonstrated [31]. Hence hospital stay is inevitably longer (average 4.43 days) for obese patients than for lean women, with increased hospitalization costs [32].

Table 25.2 Obesity associated obstetric complications

Maternal	Infant
Hypertensive disease (chronic hypertension and pre-eclampsia)	Fetal distress
Diabetes mellitus (pre and gestational)	Meconium aspiration
Urinary tract infection	Abnormal presentation
Thromboembolic disorder	Low APGAR score
Increased rate of premature delivery	Macrosomia
Increased rate of instrumental delivery	Cardiac malformations
Increased rate of Cesarean delivery	Neural tube defects (spina bifida)
Wound infection	Late fetal death
Increased rate of post-partum depression	Childhood obesity

Table 25.3 Obesity and pregnancy: general and regional anesthesia challenges

General anesthesia	Regional anesthesia and analgesia
Aspiration of gastric content	Technically difficult to perform
Failed intubation	Positioning for the block
Inadequate ventilation	Identifying appropriate landmarks
Respiratory failure	Needle length
Altered drug dosing	Definition of local anesthetic dose

25.5 Anesthesia and analgesia

Obesity in pregnancy poses a number of additional challenges for both general and neuraxial anesthesia (Table 25.3) MO parturients often require additional anesthetic or analgesic support because of their higher rate of obstetric complications, which lead to an increase in elective or emergency surgical procedures [7]. Analgesia during the labour is also demanded more often due to the more painful uterine contractions in obese patients [33].

25.5.1 General anesthesia

In the United Kingdom, the majority of maternal anesthesia-related deaths occurred under general anesthesia and only 5–19% of cesarean sections are presently performed under this kind of anesthesia [15, 34].

Airway management problems are the principal cause of maternal death with general anesthesia, and include aspiration of gastric contents, failed tracheal intubation, inadequate ventilation, and post-operative respiratory failure [35]. One in 280 attempted tracheal

intubations in obstetrics fail, compared to 1 in 2230 in the general population [36]. Although the increasing weight or BMI per se are not risk factors for difficult laryngoscopy, some authors report increased incidence of difficult or failed intubation in the MO parturient (up to 33%) as well as increased difficulty in maintaining adequate mask ventilation [37, 38].

The strategy recommended for airway management for the obese parturient is similar to the routine management of all MO patients (see Chapter 12). Potential airway management problems (fat face and cheeks, limited range of motion of the head, neck and jaw, small mouth and large tongue, excessive palatal and pharyngeal tissue, short large neck, high Mallampati (III or IV) score) should all be evaluated pre-operatively. High Mallampati score and large neck circumference are the most reliable predictors of potential intubation difficulties [39]. If a difficulty is anticipated pre-operatively an awake oral intubation with a fiberoptic bronchoscope is recommended. The nasal route is not recommended because of the characteristic engorgement of nasal mucosa during pregnancy [7].

If one plans to proceed with general anesthesia and tracheal intubation, and the pre-operative evaluation is not suggestive of a "difficult airway", the steps that need to be taken should include pre-oxygenation, placing the patient in a "ramped" position (head, upper body and shoulders significantly elevated to align the pharyngeal, laryngeal and tracheal axis) and rapid sequence intravenous induction combined with cricoid pressure [7, 40]. All necessary aids for difficult intubation, such as a short laryngoscope handle, a variety of laryngoscope blades, special laryngoscopy equipments and equipment for crico-thyroidotomy, and trans-tracheal jet ventilation, should always be available. Moreover, a second experienced anesthesiologist should be present to assist if difficulty is encountered.

Prevention of acid aspiration is important in every parturient, but even more so in obese patients [26]. For elective cesarean delivery an H_2-receptor antagonist can be given orally the night before and again on the morning of surgery along with 30 ml of non-particulate antacid to increase gastric fluid pH and decrease gastric fluid volume [19].

A study comparing three different pre-oxygenation techniques in pregnant women showed that the eight deep breaths or 3 minutes of tidal volume breathing with FiO_2 of 1.0 was better than oxygenation with only four deep breaths [41].

Succinylcholine is still the muscle relaxant of choice for airway intubation in the obstetric patient. Pseudocholinesterase levels and extracellular fluid space are both increased in obesity but, pregnancy reduces pseudocholinesterase activity [26]. However, relatively high doses of succinylcholine (1.0 mg kg^{-1} TBW) are needed for a rapid sequence anesthetic induction [42].

Extubation should be performed in a fully awake and alert patient, with adequate reversal of neuromuscular blockade and in the semi-up right position [7, 40].

25.5.2 Regional anesthesia and analgesia for labor

Regional anesthesia, when compared to general anesthesia, offers several advantages including minimal airway intervention, minimal cardiopulmonary depression, decreased intra- and post-operative opioid and sedatives requirements, decreased post-operative nausea and vomiting and shortened PACU/hospital stays [40].

The major challenges of regional anesthesia in obese pregnant are related to problems identifying appropriate landmarks, positioning of the patient prior, and after performing the block, using a needle of sufficient length, and administering the correct dose of local anesthetic. In the study by Jordan *et al.* 74.4% of obese patients required more than one attempt and 14% needed three attempts for successful epidural needle placement [43]. A failed or incomplete block may require general anesthesia and tracheal intubation, often under less than ideal conditions [44].

Obese patients normally have smaller cerebrospinal fluid (CSF) volumes than normal weight patients, and these changes are further exaggerated in the obese parturient. Decreased CSF volume due to increased abdominal pressure (obesity or pregnancy) may produce more extensive neuraxial blockade. The mechanism by which increased abdominal pressure decreases CSF volume is probably inward movement of soft tissue in the intervertebral foramen displacing CSF [45]. The epidural space volume is reduced as well, probably due to adipose infiltration and increased venous distension from aorto-caval compression and increased intra-abdominal pressure, resulting in higher spread of local anesthetic and in higher risk of hypotension and respiratory embarrassment [44].

Approximately one quarter of all obstetric anesthesia related deaths are associated with the administration of regional anesthesia (70% with epidural anesthesia, 30% with spinal anesthesia) [35].

In the sitting position the landmarks and the midline are more easily appreciated compared to the lateral position. However, attention is warranted when returning from the sitting to lateral position, since skin movements over the subcutaneous fat tissue may draw the catheter out of the epidural space. Accordingly, the patient should be allowed to return to a more neutral, relaxed position before fixing the catheter to the skin [40].

Ultrasonic guidance can aid in performing a neuroaxial block in obese patients. Ultrasound studies confirm changes in spinal anatomy and the greater skin to epidural distance during gestation [7]. However, it was also demonstrated in obese patients that BMI is a poor predictor of the distance to the epidural space, due to a disproportionate distribution of body fat. Hence it seems prudent to use as the first attempt a standard spinal or epidural needle, and only if that fails then a longer needle [19, 46].

Spinal anesthesia is often used for elective Cesarean delivery. In the obese parturient this technique may result in higher level of the neuraxial block. A single-dose injection may produce, in case of prolonged surgery time, insufficient anesthesia duration time of action [47]. Epidural anesthesia with an epidural catheter can overcome this problem, but this technique may be inadequate in more than 25% of patients due to the difficulty associated with blocking sacral nerve roots and unblocked dermatomes after catheter placement [19]. Continuous spinal anesthesia represents an alternative approach, but it is still not a routinely used method in MO parturients.

A single shot spinal anesthetic remains the most common anesthetic technique used for Cesarean section delivery [48]. It is worth reminding that a MO woman under spinal anesthesia may experience significant impairment of respiratory function [49].

A combined spinal-epidural technique represents an attractive alternative, combining the quality of spinal block with the flexibility of an epidural catheter [7, 19].

While, in the obese parturient, there is an increased incidence of accidental dural punctures, the incidence of post-dural puncture headaches (PDPH) is lower than in non-obese parturients [40, 50]. The reduced incidence of PDPH in MO patients may be the result of a decreased pressure gradient between the subarachnoid and the epidural spaces, due to engorged epidural veins and increased epidural fat, more epidural fat to plug the dural puncture once it occurs, and higher intra-abdominal pressure which retards CSF leakage [40].

The importance of satisfactory analgesia during labor is not to be under estimated for the MO parturient, due to an average longer labour and a higher rate of oxytocin induction in these patients. High pre-pregnancy weight is positively associated with the incidence of fetal macrosomia and labour abnormalities such as shoulder dystocia, and each is a known risk factor for more painful contractions and complicated labor [7].

25.6 Post-operative considerations

As previously stated, maternal obesity is associated with an increased risk of post-operative complications including hypoxemia, atelectasis and pneumonia, deep vein thrombosis and pulmonary embolism. Other complications more specific to the MO parturient are increased risk for hemorrhage following abdominal delivery, post-partum cardiomyopathy, endometritis, wound infection and dehiscence [7, 19].

Pain management should be adequate in the post-operative period to facilitate early mobilization and chest physiotherapy. Post-Cesarian patients may benefit from continued epidural analgesia or intravenous opioid patient-controlled analgesia. The use of non-opioid analgesic adjuncts may reduce the total dose of opioids [7, 19].

25.7 Conclusions

The prevalence of obesity is increasing among pregnant women. The peri-operative management of the MO parturient is associated with increased risks and difficulties hence demanding a multidisciplinary approach. Anticipating potential complications is critical in reducing maternal and peri-natal morbidity and mortality. Regional anesthesia offers major advantages for the obese parturient compared to general anesthesia. However, there is a paucity of information as to how obese patients tolerate regional anesthesia, what are the appropriate doses of local anesthetics, and whether the risk of minor and serious complications is increased, and what is the best technique to use.

References

1. Ehrenberg Hm, Dierker L, Milluzzi BM. Prevalence of maternal obesity in an urban center. *Am J Obstetr Gynecol* 2002; **187**: 1189–93.
2. Edwards LE, Hellerstedt WL, Alton IR, Story M, Himes JH. Pregnancy complications and birth outcomes in obese and normal-weight women: effects of gestational weight change. *Obstet Gynecol* 1996; **87**: 389–94.
3. Kristensen J, Vestergaard M, Wisborg K, Kesmodel U, Secher NJ. Pre-pregnancy weight and the risk of stillbirth and neonatal death. *Int J Obstetr Gynecol* 2005; 112: 403–8.

4. Whitaker RC. Predicting preschooler obesity at birth: the role of maternal obesity in early pregnancy. *Pediatrics* 2004; **114**: 29–36.
5. Boney CM, Verma A, Tucker R, Vohr BR. Metabolic syndrome in childhood: association with birth weight, maternal obesity, and gestational diabetes mellitus. *Pediatrics* 2005; **115**: e290–6.
6. Sheiner E, Levy A, Menes TS, Silverberg D, Katz M, Mazor M. Maternal obesity as an independent risk factor for caesarean delivery. *Paediatr Perinat Epidemiol* 2004; **18**: 196–201.
7. Saravanakumar K, Rao SG, Cooper GM. Obesity and obstetric anaesthesia. *Anaesthesia* 2006; **61**: 36–48.
8. Fegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among US adults, 1999–2000. *JAMA* 2002; **288**: 1723–27.
9. Kim SY, Dietz PM, England L, Morrow B, Callaghan WM. Trends in pre-pregnancy obesity in nine states, 1993–2003. *Obesity* 2007; **15**: 986–93.
10. Department of Health, London. Health survey for England 2002 – trends.
11. Galtier-Derture F, Boegner C, Bringer J. Obesity and pregnancy: complications and cost. *Am J Clin Nutr* 2000; **71** (suppl.): S1242–48.
12. Nucci LB, Scmidt MI, Duncun BB. Nutritional status of pregnant women: prevalence and associated pregnancy outcomes. *Revista de Saude Publica* 2001; **35**: 502–7.
13. Cameron AJ, Welborn TA, Zimmet PZ. Overweight and obesity in Australia: the 1999–2000 Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Med J Aust* 2003; **178**: 427–32.
14. Callaway LK, Prins JB, Chang AM, McIntyre HD. The prevalence and impact of overweight and obesity in an Australian obstetric population. *Med J Aust* 2006; **184**: 56–9.
15. Lewis G (ed) Confidential enquiry into maternal and child health, saving mothers' lives: reviewing maternal deaths to make motherhood safer 2003–2005. The Seventh Report on Confidential Enquiries into Maternal Deaths in the United Kingdom. CEMACH, London, 2007.
16. Sukalich S, Mingione MJ, Glantz JC. Obstetric outcomes in overweight and obese adolescents. *Am J Obstetr Gynecol* 2006; **195**: 851–5.
17. Chang AB. Physiological changes of pregnancy. In: Chesnut DH, ed *Obstetric anesthesia: principles and practice*, 3rd edn. Philadelphia: Elsevier Mosby, 15–36; 2004.
18. Galtier F, Raingeard I, Renard E, Boulot P, Bringer J. Optimizing the outcome of pregnancy in obese: from pregestational to long-term management. *Diabetes & Metab* 2008; **34**: 19–25.
19. Soens MA, Birnbach DJ, Ranasinghe JS, Zundert A. Obstetric anesthesia for obese and morbidly obese patient: an ounce of prevention is worth more than a pound of treatment. *Acta Anaesthesiol Scand* 2008; **52**: 6–19.
20. Tsueda K, Debrand M, Zeok SS, Wright BD, Griffin WO. Obesity supine death syndrome, reports of two morbidly obese patients. *Anesth Analg* 1979; **58**: 345–7.
21. Unterborn J. Pulmonary function testing in obesity, pregnancy and extremes of body habitus. *Clin Chest Med* 2001; **22**: 759–767.
22. Eng M, Butler J, Bonica JJ. Respiratory function in pregnant obese women. *Am J Obstetr Gynecol* **123**: 241–5.
23. Lefcourt LA, Rodia JF. Obstructive sleep apnea in pregnancy. *Obst Gynecol Surv* 1996; **51**: 503–6.
24. Roush SF, Bell L. Obstructive sleep apnea in pregnancy. *J Am Board Fam Pract* 2004; **17**: 1036–46.
25. Abrams B, Parker J. Overweight and pregnancy complications. *Int J Obes* 1988; **12**: 293–303.
26. Roberts RB, Shirley MA. Reducing the risk of acid aspiration during cesarean section. *Anesth Analg* 1974; **53**: 859–68.
27. Wolf M, Kettyle E, Sandler L, Ecker JL ; Roberts J, Thadhani R. Obesity and preeclampsia: the potential role of inflammation. *Obstetr Gynecol* 2001; **98**: 757–61.
28. Abrams BF, Laros PK Jr. Pregnancy weight, weight gain, and birth weight. *Am J Obstet Gynecol* 1986; **154**: 503–9.
29. Naeye Rl. Maternal body weight and pregnancy outcome. *Am J Clin Nutr* 1990; **52**: 273–9.
30. Andreasen KR, Andersen ML, Schant AL. Obesity and pregnancy. *Acta Obstet Gynecol Scand* 2004; **83**: 1022–9.
31. Dietl J. Maternal obesity and complications during pregnancy. *J Perinat Med* 2005; **33**: 100–5.
32. Grundy MA, Woodcock S, Attwood SE. The surgical management of obesity in young women: consideration of the mother's and baby's health before, during, and after pregnancy. *Surg Endosc* 2008; **22**: 2107–16.
33. Melzack R, Krinch R, Dobkin P. Severity of labour pain: influence of physical as well as psychologic variables. *Can Med Assoc* 1984; **130**: 579–84.
34. NHS. Maternity Statistics, England: 2002–03. Bulletin 10; *Government Statistical Services*. 2004; London: Department of Health.
35. Hawkins JL. Maternal mortality: anesthetic implications. *Anesthesiol Clin* 2002; **40**: 1–11.
36. Munnur U, de Boisblanc B, Suresh MS. Airway problems in pregnancy. *Crit Care Med* 2005; **33** (10 Suppl): S259–68.
37. Bernardo PD, Jenkins JG. Failed tracheal intubation in obstetrics: a 6 year review in UK region. *Anaesthesia* 2000; **55**: 685–94.

38. D'Angelo R, Dewan DD. Obesity. In: Chesnut DH, eds. *Obstetric Anesthesia: Principle and practice*. Philadelphia Elsvier Mosby, 893–903; 2004.
39. Brodsky JB, Lemmens HJ, Brock-Utne JG, Vierra M, Saidman LJ. Morbid obesity and tracheal intubation. *Anesth Analg* 2003; **94**: 732–6.
40. Vallejo MC. Anesthetic management of the morbidly obese parturient. *Curr Opin Anaesthesiol* 2007; **20**: 175–80.
41. Chiron B, Laffon M, Ferrandiere M. Standard preoxygenation technique versus two rapid techniques in pregnant patients. *Int J Obstet Anesth* 2004; 1**3**, 11–14.
42. Lemmens HJM, Brodsky JB. The dose of succinylcholine in morbid obesity. *Anesth and Analg* 2006; **102**: 438–42.
43. Jordan H, Perlow MD, Mark A. Massive maternal obesity and perioperative cesarean morbidity. *Am J Obstet Gynecol* 1994: **170**: 560–5.
44. Brodsky JB, Lemmens HJM. Regional anesthesia and obesity. *Obes Surg* 2007: **17**: 1146–9.
45. Hogan QH, Prost R, Kulier A. Magnetic resonance imaging of cerebrospinal fluid volume and the influence of body habitus and abdominal pressure. *Anesthesiology* 1996; **84**: 1341–9.
46. Watts RW. The influence of obesity on the relationship between body mass index and the distance to the epidural space from the skin. *Anaesth Intens Care* 1993; **21**: 309–10.
47. Kuczkowski KM, Benumof JL. Repeat caesarean section in a morbidly obese parturient: a new anesthetic option. *Acta Anaesthesiol Scand* 2002; **46**: 753–5.
48. Coker LL. Continuous spinal anesthesia for cesarean section for a morbidly obese parturient patient: a case report. *AANA Journal* 2002; **70**: 189–92.
49. Regali A, von Ungern-Sternberg BS, Reber A, Schneider MC. Impact of spinal anaesthesia on peri-operative lung volumes in morbidly obese female patients. *Anaesthesia* 2006; **61**: 215–21.
50. Whitty RJ. Maxwell CV, Carvalho JCA. Complications of neuroaxial anesthesia in an extreme morbidly obese patient for cesarean section. *J Obstetr Anesthes* 2007; **16**: 139–44.

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