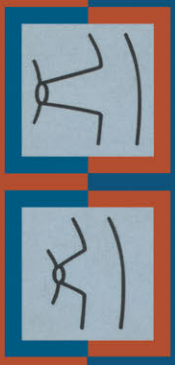

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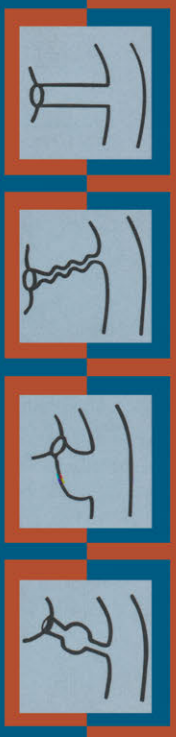
Pediatric Cardiology Updates



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Pediatric Cardiology Updates

With 49 Figures

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Foreword

At the time of my pediatric residency training at the Johns Hopkins Hospital in Baltimore in the 1940s, I witnessed the birth of modern pediatric cardiology. The successful performance of the Blalock-Taussig "blue baby" operation at Johns Hopkins attracted worldwide attention and stirred excitement and expectations. The explosion of new information and diagnostic techniques over the past half-century have fulfilled many of these expectations.

The continuing quest for additional knowledge and the application of newer diagnostic and surgical procedures are going on in many centers throughout the world. The pediatric cardiologists in the Asian Pacific countries stand out for their scholarly contributions, and their most recent scientific papers make up the contents of this book. Professor Hung-Chi Lue, the editor of this volume, is the person most responsible for the development and prominence of pediatric cardiology in the Asian Pacific region. After completing his medical and pediatric training in his native Taiwan, Dr. Lue spent two years in pediatric cardiology under the late Dr. Sidney Blumenthal at the Babies Hospital, Columbia University, New York. Upon his return to Taiwan in 1967, Dr. Lue established the Division of Pediatric Cardiology at the National Taiwan University, which he still actively directs. Dr. Lue has held many international offices and has received numerous awards and invitations to lecture throughout the world. Above all, however, he is proudest of his founding and directing the Cardiac Children's Foundation of the Republic of China. Our mutual interest in the field of rheumatic fever has brought us together many times over the past 20 years. Dr. Hung-Chi Lue is an extraordinarily multitalented person and I value greatly our friendship.

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Preface

In the mid-1990s, pediatricians and cardiologists have witnessed a number of breakthroughs and advances in the field of pediatric cardiology.

The advent of powerful invasive and noninvasive diagnostic techniques such as color Doppler echocardiography, computerized tomography, and magnetic resonance imaging has revolutionized traditional diagnostic approaches, thus making possible the diagnosis and treatment of many complex congenital heart diseases.

Catheter-directed treatment of some congenital cardiac lesions with balloons and stents has become the procedure of choice, although further discussion of the indications and refinement of techniques are still needed. Cardiac arrhythmias in infancy and childhood are being given more attention with the application of radio-frequency ablation and the accumulation of considerable experience.

Recent resurgence of acute rheumatic fever in the United States, and changing patterns of rheumatic heart disease in developing countries have once again aroused the concern and interest of pediatricians and cardiologists worldwide. Whether the gold standard of monthly benzathine penicillin prophylaxis for rheumatic fever should be modified has been an issue of disagreement. Bacterial endocarditis may effectively be prevented if appropriate measures are taken.

To update pediatric cardiology, the First Asian–Pacific Symposium on Pediatric Cardiology was held in Taipei November 4–6, 1994. More than 20 world-class experts, 24 national delegates of the Asian–Pacific Society of Cardiology, and many other pediatricians, cardiologists, and surgeons came to Taipei and participated in the Symposium. The manuscripts read at the Symposium were edited and are presented in this monograph.

We believe that the subjects included here are of special interest to pathologists, pediatricians, cardiologists, and surgeons. This book will be of great value to the many physicians who are caring for infants and children as well as adults with heart disease.

The First Asian–Pacific Symposium on Pediatric Cardiology and the publication of this monograph were made possible through the sponsorship of the International Society and Federation of Cardiology, the R.O.C. Society of Cardiology, the Chinese Taipei Pediatric Association, the Department of Health and the National Science Council of the Executive Yuan, and the Cardiac Children's Foundation, R.O.C. The editors are grateful to all speakers, moderators, and staff members of the Organizing Committee, especially to Drs. C.R. Hung, W.J. Su, B.T. Hwang, M.H. Wu, J.K.

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The Diagnostic Approach to Single Ventricle

YONG-SOO YUN

Summary. Hearts with a single ventricle frequently have complex anomalies, such as atrial isomerism, involving the systemic and pulmonary veins. From the clinical and surgical points of view, the morphology and size of the pulmonary arteries and atrioventricular (AV) valve competency are more important than other lesions in these anomalies. If the AV valve is undivided, like the endocardial cushion valve, there may be significant regurgitation; if one of the divided valves is atretic or has no connection, however, the other valve may be more competent or show mild regurgitation. This is important for the long-term prognosis of those patients who undergo the modified Fontan procedure or total cavopulmonary connection surgery. A single diagnostic tool is usually not satisfactory for the study of single ventricles. Echocardiography, angiocardiography, and sometimes cardiac magnetic resonance imaging are needed, complementing each other, for correct diagnosis and assessment of the complex cardiac lesions.

Key words. Single ventricle—Diagnosis—Univentricular heart—Atrioventricular valve

Introduction

The heart with one main chamber is an uncommon anomaly, having an incidence of 0.7%–1.0% of all congenital heart disease [1]. This anomaly has been the source of increased interest and controversy in its embryological, pathological, and surgical aspects. Various terms, such as "single" or "common" ventricle [2], "primitive ventricle" [3], "double inlet ventricle" [4,5], and "univentricular atrioventricular connection" (UAVC) [6] have been applied, and the embryological explanation and diagnostic criteria differ according to the nomenclature.

The classification of this anomaly is based on the morphological type of the main chamber and the status of the atrioventricular connection, and is important from the surgical standpoint because the cardiac conduction system and distribution of coronary arteries are closely related to the morphological classification [7]. The term single ventricle is used here to describe the family of complex lesions in which a single

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ventricular chamber receives blood from both atria via two separate or a single common atrioventricular (AV) valve.

Single ventricles are classified, according to the morphology of the main ventricular chamber, into (1) the left ventricular type, (2) the right ventricular type, and (3) the (rare) indeterminate ventricle type (Fig. 1) [8]. The left and right ventricular types possess two ventricular chambers with one main chamber and a second rudimentary chamber, but the third (indeterminate) type has no rudimentary chamber. The types of AV connections are (1) an absent right atrioventricular connection, (2) a double-inlet atrioventricular connection, and (3) an absent left atrioventricular connection [9]. A segmental approach to the analysis of each cardiac segment is helpful in the study of complex cardiac anomalies, including the univentricular heart [10]. Clinical analysis of the cardiac segment, however, is often insufficient or equivocal. The morphological differences between the left and right ventricular types of single ventricles are listed in Table 1.

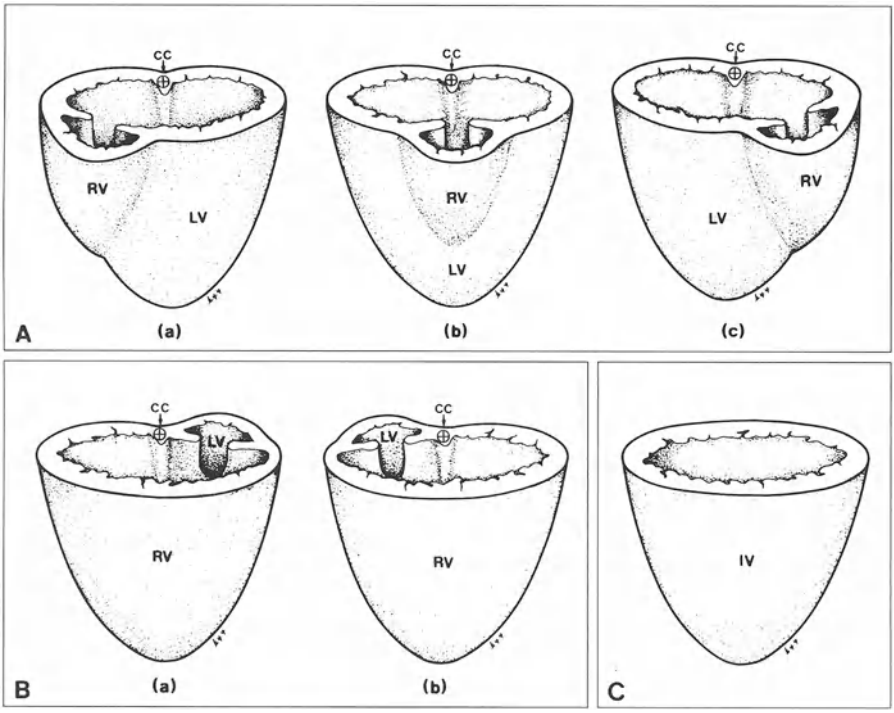


FIG. 1A–C. Types of single ventricle. **A** Double-inlet left ventricle. Both atria are connected to the main chamber of left ventricular morphology. The rudimentary right ventricle (*RV*) (outlet chamber) may be right anterosuperior (*a*), directly anterosuperior (*b*), or left anterosuperior (*c*) to the left ventricle (*LV*). The ventricular septum never extends to the crux cordis (*CC*). **B** Double-inlet right ventricle. Both atria are connected to the main chamber of right ventricular morphology. The rudimentary LV (trabecular pouch) may be left posteroinferior (*a*) or right posteroinferior (*b*) to the RV. The ventricular septum extends to the CC. **C** Double-inlet indeterminate ventricle (*IV*). Both atria are connected to the solitary ventricular chamber of indeterminate morphology. Neither the rudimentary ventricle nor the ventricular septum is found

TABLE 1. Morphological differences between the left ventricular (LV) and right ventricular (RV) types in single ventricles

Segmental description	LV type	RV type
Atrial situs	Solitus	Isomerism frequent
Atrioventricular valve		Common valve frequent
Trabeculae of main chamber	Fine	Coarse
Position of rudimentary chamber	Anterior to septum	Posterior to septum
Character of rudimentary chamber	Outlet chamber	Trabecular pouch
Septum–crux connection	Present	Absent
Ventriculoarterial connection	Discordant or concordant	Double or single outlet
Prominent coronary artery	Anterior descending coronary artery	Posterior descending coronary artery

TABLE 2. Types of single ventricle[a]

Type	Condition	*n*
Left ventricle type, 33	Double inlet	4
	Absent right AV connection	18
	Absent left AV connection	11
Right ventricle type, 28	Double inlet	8
	Absent right AV connection	4
	Absent left AV connection	16
Indeterminate ventricle type, 10		

AV, Atrio-ventricular.

[a] Seoul National University Hospital, January 1991–June 1994; $n = 71$.

Because of the surgical techniques [11] involved in separating the systemic and pulmonary circulation and their similarities in functional ventricular architecture, it is useful to group these types of heart together, especially for clinicians. A total of 71 patients with single ventricle, excluding tricuspid atresia and hypoplastic left heart syndrome, were encountered during the past 4 years at the Seoul National University (Table 2).

Diagnosis of Single Ventricle

A heart with a single ventricle should be analyzed by delineating the atrial situs with systemic and pulmonary venous return, the mode of AV connection, the spatial relation between ventricles, the volume of ventricles, the location and size of any ventricular septal defect, the presence of any obstruction to the outflow tracts, and the degree of AV valve regurgitation [8]. There is no single standard method to obtain all the information about these lesions, because no two hearts within the spectrum of single ventricle are identical.

Clinical Findings

Most patients present early in life with cyanosis caused by inadequate pulmonary blood flow or congestive heart failure, if pulmonary blood flow is unobstructed or if

pulmonary venous return is obstructed [12]. These findings, however, are not sufficient to distinguish single ventricle from other cyanotic heart diseases.

Chest Roentgenography

The findings on chest roentgenography depend on the degree of pulmonary outflow obstruction. The sidedness of a stomach bubble may provide information about the abdominal situs. If atrial isomerism is suspected, high-kilovolt films or tomograms may allow evaluation of the bronchial anatomy [13].

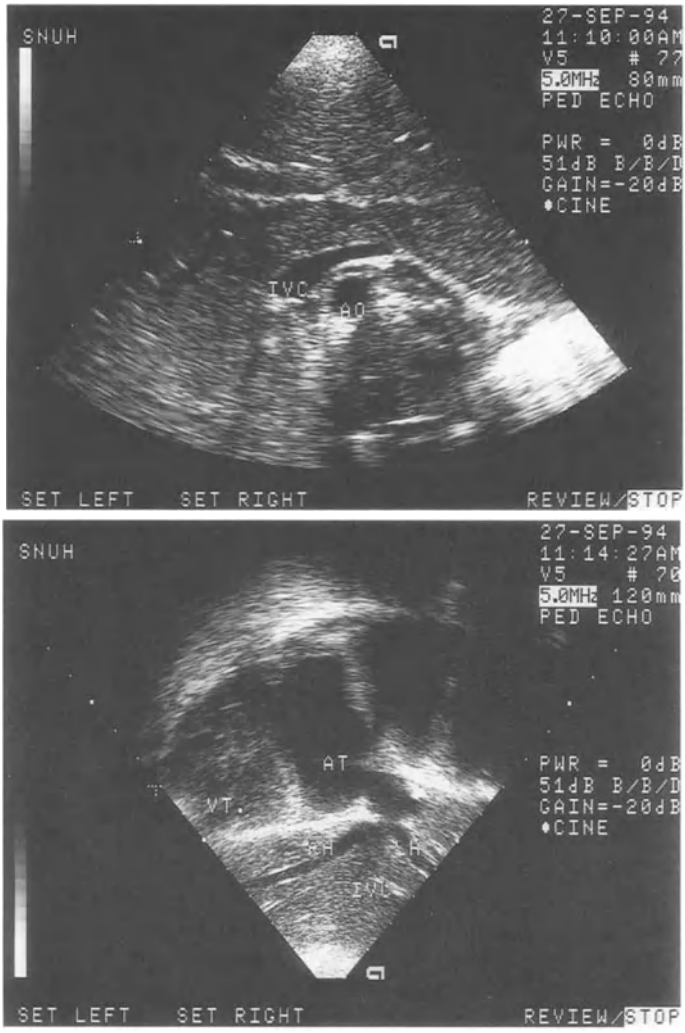


FIG. 2. *Top*: Transverse subxiphoid view of the abdomen in patients with asplenia. The aorta and IVC both lie to the right of the midline, and the IVC is anterior and lateral to the aorta. *Bottom*: Subxiphoid parasagittal view shows the hepatic segment of the IVC connecting with the left-sided atrium in same patient. *AT*, Atrium; *AO*, aorta; *LH*, left hepatic vein; *RH*, right hepatic vein; *IVC*, inferior vena cava; *VT*, ventricle

Electrocardiographic Findings

The electrocardiographic findings are quite variable. There is generally sinus rhythm, and the P-R interval is usually normal, although first-degree atrioventricular block was present in 30% of the patients reported by Gillette [14]. Rarely, congenital complete heart block is present; these findings, however, are nonspecific.

2-D and Doppler Echocardiography

Two-dimensional (2-D) echocardiography greatly reduces the time required to obtain this information and provides much more accurate information about spatial rela-

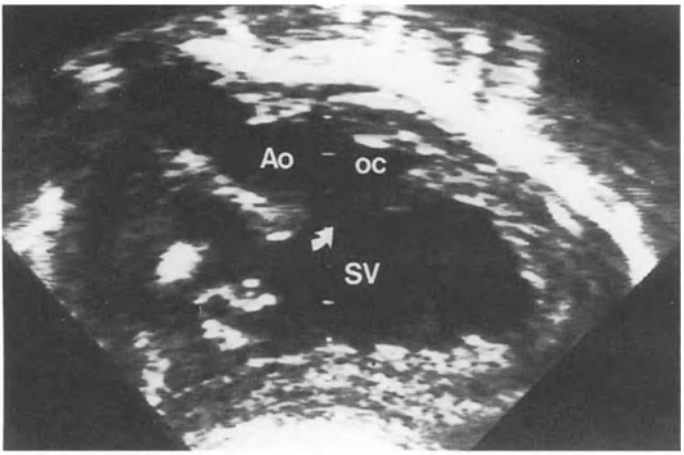


FIG. 3. Left ventricular (*LV*) type single ventricle (*SV*) with left anterior outlet chamber (*OC*) and L-transposition aorta (*AO*). Subcostal four-chamber view anterior projection

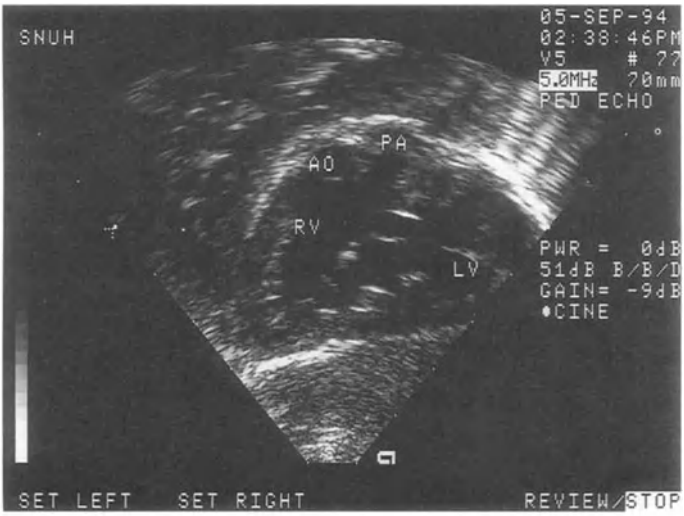


FIG. 4. Right ventricular (*RV*) type single ventricle (*RV*) with left posteriorly located rudimentary left ventricle (*LV*). *PA*, Pulmonary artery. Subcostal short-axis view

tions [15]. Clues to the situs are obtained from the systemic venous anatomy [16] Fig. 2). The type and mode of AV connection are well seen. Straddling and overriding of AV valves may be assessed more accurately by echocardiography than by angiography. When an outlet chamber is present, the chamber and the size and location of the ventricular septal defect can usually be seen (Fig. 3). A small posterior left ventricle associated with a dominant right ventricle may be seen, or it may be too small to be seen (Fig. 4). The differentiation of the morphological type of the main ventricle may often be inferred from the associated nondominant chamber, but the apical

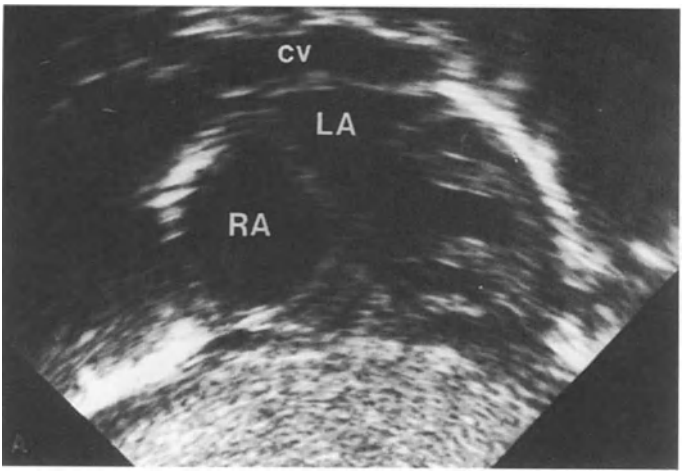


FIG. 5. A common pulmonary vein (*CV*) is seen posterior to the left atrium (*LA*) in a patient with total anomalous pulmonary venous connection. *RA*, Right atrium

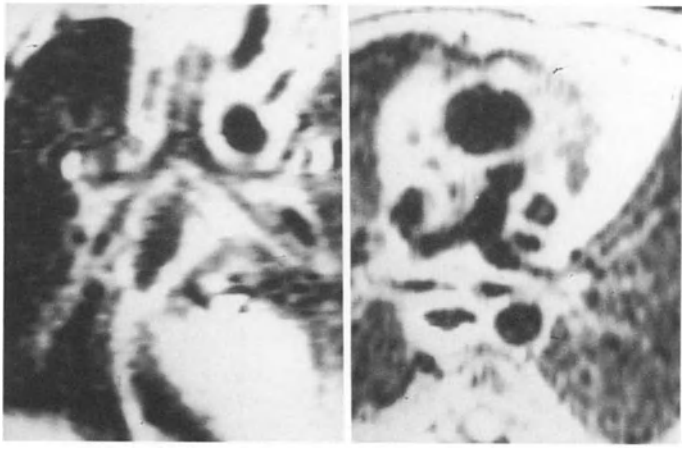


FIG. 6. Coronal (*left*) and axial (*right*) magnetic resonance (*MR*) images of a patient with asplenia show bilateral right bronchus and superior vena cava

trabecular pattern of the ventricles is not reliably discernible with current techniques [17].

The ventriculoarterial connection and its spatial relations can usually be seen, with the presence of subvalvar or valvar stenosis. This usually requires both parasternal long- and short-axis views. From the suprasternal notch, the sidedness of the arch, bifurcation of the pulmonary arteries, and the systemic venous return can also be seen. In the presence of total anomalous pulmonary venous return, multiple suprasternal and subcostal views usually demonstrate the location of the connection between the pulmonary venous confluence and the systemic vein (Fig. 5). Doppler technique allows detection of the flow in the ductus, insufficiency of the AV valves, and differentiation of pulmonary stenosis or atresia.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) currently provides little information not obtained more quickly, precisely, and cheaply by 2-D and Doppler echocardiography. However, this modality may be useful in patients with poor windows for echocardiography [18]. Deep structures, such as systemic and pulmonary veins, and the pattern of bronchus can be evaluated (Fig. 6). Sometimes, the blind pouch of a rudimentary chamber in the LV type of single ventricle could be detected by this technique (Fig. 7). The advantages and limitations of MRI are listed in Table 3.

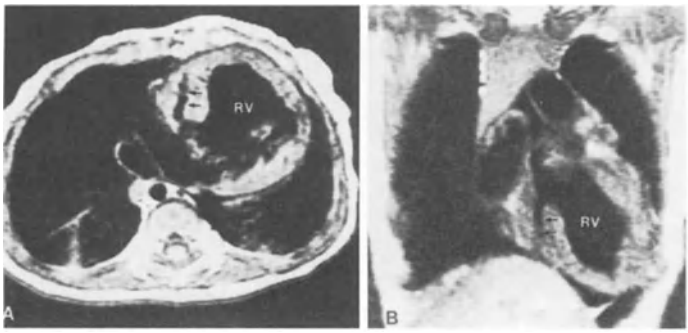


FIG. 7A,B. Axial (**A**) and coronal (**B**) MR images of RV type single ventricle. A small rudimentary left ventricle (*arrows*) occupies the right side of the large right ventricle (*RV*)

TABLE 3. Magnetic resonance imaging (MRI)

Advantages	Limitations
Wide field of view	Too expensive
Free from air, bone, and depth restrictions	Relatively thick section
Natural contrast of flowing blood	Motion artifact
Visualization of mediastinal structure	Long examination time
Unlimited imaging planes	ECG gating necessary
Objective images	Pacemaker problem
	Impossible functional study

Cardiac Catheterization

Oxygen saturation, pressure measurement, and catheter course in each chamber and the great vessels can give us additional or confirmatory data on the basis of the information obtained by 2-D and Doppler echocardiography. In our laboratory, we usually do measure the pressure difference across the bulboventricular foramen in the LV type of single ventricle without pulmonary stenosis after occluding one of the pulmonary artery branches with a balloon catheter. With this occlusion, the amount of aortic flow will increase and the pressure difference across the bulboventricular foramen can be augmented, so that we can estimate whether the foramen will become obstructed after surgery.

Angiography

Angiography has played a major role in the study and understanding of the heart with a single ventricle [19]. While echocardiography has emerged as a powerful tool for evaluating the anatomy of these hearts, angiography remains essential for the evaluation of the details less well demonstrated echocardiographically (Fig. 8). Axial angiography allows clearer demonstration of AV valve anatomy, tiny ventricular chambers, outflow tracts, and peripheral pulmonary arteries (Fig. 9) [20]. Four-chamber and long-axial oblique views are the two most important views (Fig. 10).

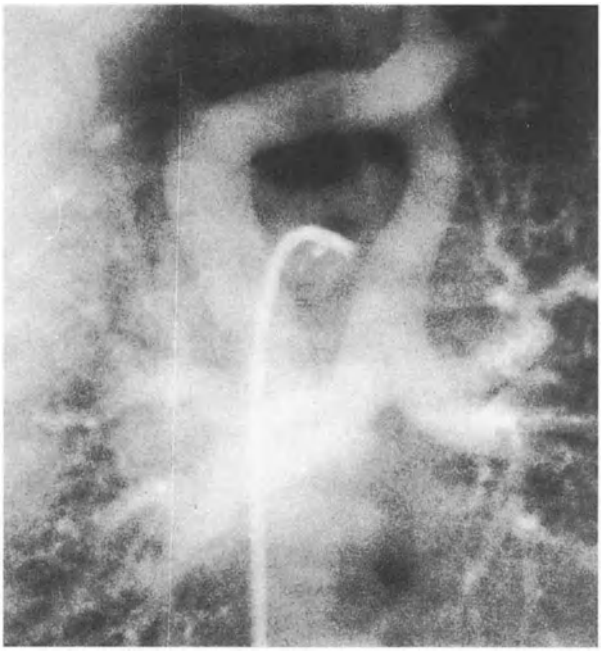


FIG. 8. Levophase of pulmonary arteriogram shows a total anomalous pulmonary venous connection to the vertical vein, coursing into the innominate vein, superior vena cava, and ultimately the right atrium

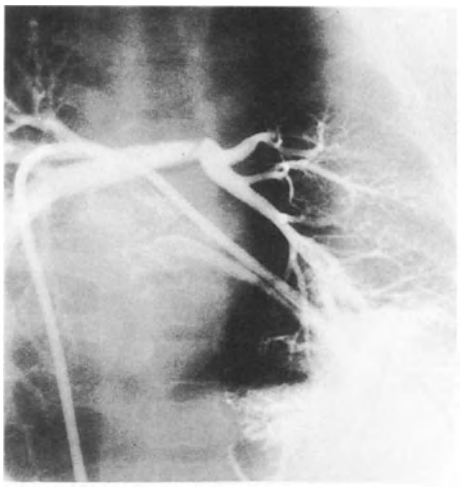
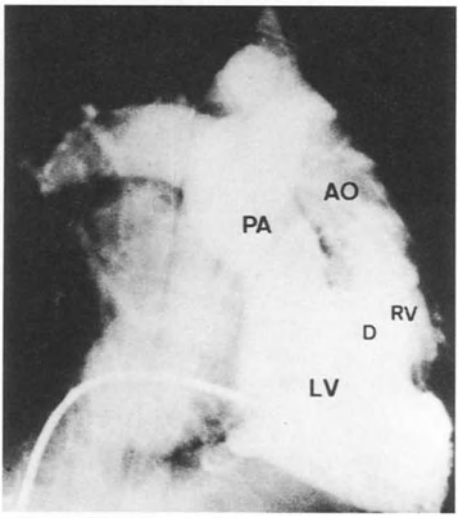
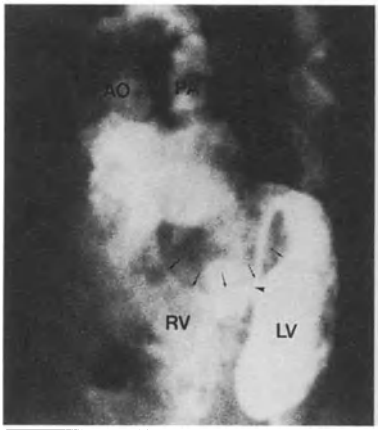


FIG. 9. Pulmonary vein wedge angiogram shows confluent pulmonary arteries with no main pulmonary artery trunk in a patient with single ventricle and dextrocardia





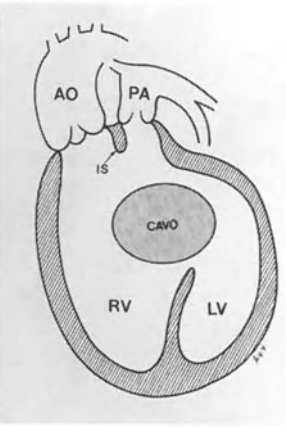


FIG. 10. *Top*: Left ventriculogram in right anterior oblique view shows a double-inlet left ventricle (*LV*) with rudimentary right ventricle (*RV*), transposition of the great arteries (*AO, PA*), and the ventricular septal defect (*D*). *Bottom*: Left ventriculogram in four-chamber view and its diagrammatic representation in a patient with right atrial isomerism and double-inlet right ventricle. The common atrioventricular orifice (*arrows; CAVO*) is mainly connected to the right ventricle. Both great arteries arise from the right ventricle. *IS*, Infundibular septum

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The Diagnostic Approach to Double-Outlet Right Ventricle

LUIS M. MABILANGAN

Summary. Double-outlet right ventricle (DORV) is a rare and complex congenital heart disease wherein both great arteries are connected to the morphologic right ventricle. Because of its diverse anatomical variations, there are several definitions of DORV by different investigators. The modified definition by Lev, Anderson, and Kirklin has been applied in this study. Among the different diagnostic tools, two-dimensional echocardiography is the most important, supplemented by cardiac catheterization and angiocardiography.

Key words. Double-outlet right ventricle—Two-dimensional echocardiography—Cardiac catheterization—Angiography

Introduction

Double-outlet right ventricle (DORV) is a complex congenital heart disease wherein both great arteries are connected to the morphologic right ventricle [1]. It is not simply a single malformation or a single group of malformations as there is a wide and bewildering diversity of anatomical variations. Such heterogenous findings have been described by several investigators with their own definitions. For example. Neufield et al. [2] defined it as follows: (1) both great arteries and arterial trunks arise exclusively from the morphological right ventricle; (2) neither semilunar valve is in fibrous continuity with either atrioventricular valve; and (3) usually a ventricular septal defect (VSD) is present that represents the only outlet of the left ventricle.

Van Praagh et al. [3,4] defined DORV as both great arteries originating either from the infundibulum, which is aligned with the right ventricle (RV), or one great artery arising from the infundibulum and the other in direct continuity with the RV portion of the atrioventricular (AV) canal, i.e., the tricuspid valve or the RV portion of the common AV valve or the RV portion of the straddling mitral valve.

Lev et al. [5] and Anderson et al. [6] gave a definition requiring less rigid criteria: (1) one complete arterial trunk and at least half of the other arterial trunk emerge from the right ventricle; and (2) there may or may not be mitral–aortic or mitral–pulmonary discontinuity. Kirklin et al. [7] modified the foregoing with the 50%

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rule of overriding. In our setting, we have adopted this modified definition by Lev, Anderson, and Kirklin.

Variants of Double-Outlet Right Ventricle

DORV is an uncommon malformation accounting for fewer than 1% of all congenital malformations [8]. At the Philippine Heart Center from 1987 to 1993, DORV constituted 1.9% of the 8527 cases of congenital heart disease. The Department of Pathology of the above institution found 40 cases of DORV, or 2.3% of the 1775 autopsied cases, from 1975 to 1989. At the Philippine General Hospital Department of Pediatrics, among the 1288 cases of congenital heart diseases diagnosed by echocardiography from October 1990 to August 1994, DORV accounted for 33 cases, or 2.6% of the total.

The variants of DORV can generally be grouped according to the relationships of the great arteries, which also provides clues to the type of associated VSD. Types of great artery relationships are (1) the normal relationship, with the aorta to the right and posterior of the pulmonary artery; (2) the side-by-side relationship, in which the aorta is to the right of the pulmonary artery and the semilunar valves lie approximately in the same transverse plane; (3) dextroposition, with the aorta to the right and anterior to the pulmonary artery; and (4) levoposition, with the aorta to the left and anterior to the pulmonary artery (Fig. 1).

There are four types of VSD in DORV (Fig. 2): (1) the subaortic type; (2) the subpulmonic type; (3) the doubly committed subarterial type; and (4) the remote type, the muscular or atrioventricular canal defect type. Common variants [9] are (1) subaortic VSD, with the aorta to the right of the pulmonary trunk along with pulmonary stenosis; (2) subpulmonary VSD, with the aorta to the right of the pulmonary trunk; and (3) subaortic VSD, with the aorta to the right of the pulmonary trunk in the

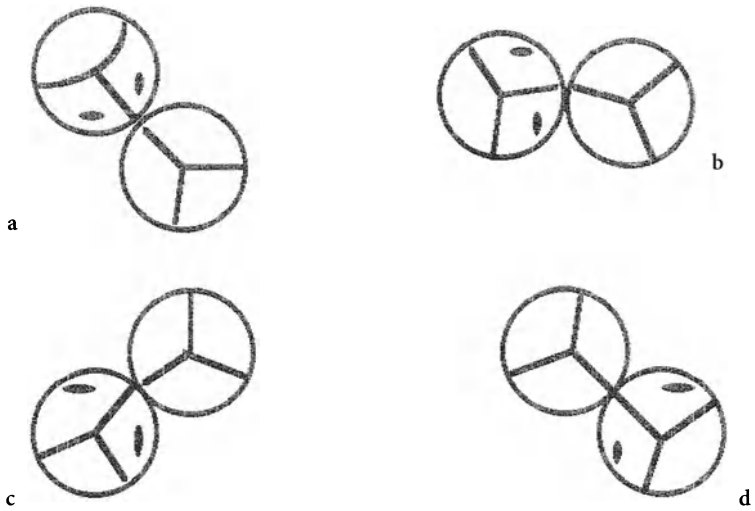

FIG. 1a–d. Types of great artery relationships. **a** Normal relation. **b** Side by side. **c** Dextroposition. **d** Levoposition

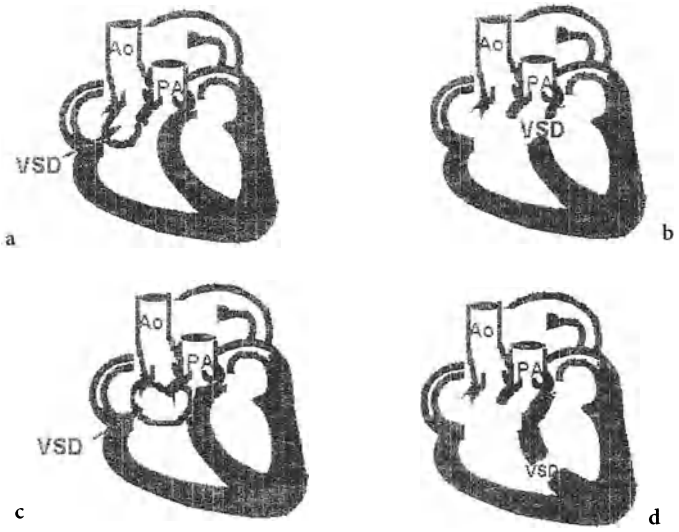

FIG. 2a–d. Four types of ventricular septal defect in double-outlet right ventricle. **a** Subaortic. **b** Subpulmonic. **c** Doubly committed. **d** Remote. *VSD*, Ventricular septal defect; *Ao*, aorta; *PA*, pulmonary artery

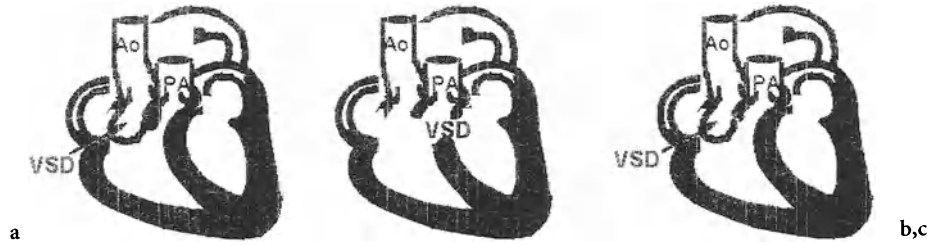

FIG. 3a–c. Common variants. **a** Subaortic VSD; aorta to the right of pulmonary artery, with pulmonary stenosis. **b** Subpulmonary VSD; aorta to the right of the pulmonary artery. **c** Subaortic VSD; aorta to the right of the pulmonary artery with no pulmonary stenosis. (Modified from [8])

absence of pulmonary stenosis (Fig. 3). Less common variants [8] are (1) double committed VSD; (2) uncommitted VSD; and (3) subaortic VSD with the aorta to the left of the pulmonary trunk along with pulmonary stenosis (Fig. 4).

Associated Cardiac Defects

The common associated defects observed by Wilkinson et al. [8] in 84 specimens of DORV are pulmonary stenosis, 31 (37%); atrial septal defect, 19 (23%); coarctation of the aorta, 16 (19%); mitral stenosis, 7 (11%); straddling mitral valve, 6 (7%); and hypoplastic left ventricle, 5 (6%).

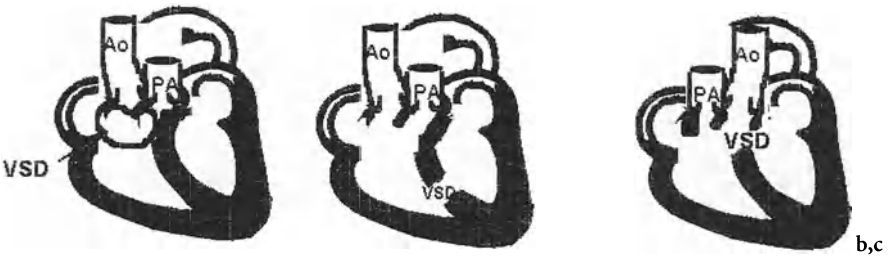

FIG. 4a–c. Less common variants. **a** Double committed VSD. **b** Uncommitted VSD. **c** Subaortic VSD; aorta to the left of pulmonary artery with pulmonary stenosis. (Modified form [8])

The associated cardiac defects observed in the Department of Pathology, Philippine Heart Center, in 40 autopsied cases of DORV were pulmonary stenosis, 17 (43%); patent ductus arteriosus, 16 (40%); atrial septal defect, (20%); coarctation of the aorta, 6 (15%); pulmonary atresia, 5 (13%); mitral valve abnormality, 3 (8%); and hypoplastic left ventricle, 2 (5%).

Clinical Features

The clinical features of DORV are dependent on its anatomy and the associated cardiac anomalies. The spectrum of clinical features is wide, ranging from the picture of a large VSD to transposition of the great arteries to tetralogy of Fallot.

There is no characteristic electrocardiographic pattern, although most cases show right ventricular hypertrophy. A significant left ventricle is seen when associated with the Taussig–Bing variety. Chest radiograms are nonspecific. Heart size varies, depending on the anomalies present, from normal to cardiomegaly. Similarly, pulmonary vascularity appears as decreased or increased.

Diagnosis of Double-Outlet Right Ventricle

The diagnosis of DORV can be made with confidence by the use of two-dimensional echocardiography [9]. One can also demonstrate the relationship of the VSD to the arterial outlets, the presence of arterial outlet narrowing or obstruction, and the coexistence of associated anomalies, especially those involving the AV valves. The parasternal long-axis view is most helpful in demonstrating that both great arteries arise predominantly or entirely from the right ventricle. Furthermore, discontinuity between the aortic leaflet of the mitral valve and the arterial valves may be present, although this finding is not always observed in DORV. The ventricular origin of a great artery can be established with a high degree of accuracy through the combined use of long-axis and serial short-axis views. The interrelationship of the great arteries, their relative sizes, and the presence or absence of valvular or subvalvular obstruction may also be seen. Two-dimensional echocardiography is also of particular value in establishing the presence of major AV valve abnormalities such as a common AV orifice or straddling of the mitral or tricuspid valve across the interventricular septum, which is of great importance to the surgeon.

Cardiac catheterization and angiocardiography [10] are invasive diagnostic tools with two important objectives. First, the ventriculoarterial connection must be documented, and second, all surgical aspects of malformation must be assessed. In obtaining the hemodynamic data, one must pay attention to the assessment of any significant systolic pressure gradient between the left and right ventricles suggestive of a restrictive ventricular septal defect. Any diastolic pressure gradient across the valve should also be assessed. In this respect, a left ventriculogram is essential. Measurement of the pulmonary arterial pressure and calculation of the flow and resistance are also necessary to detect any obstruction at the pulmonary and systemic outlet.

Angiocardiography should include a left and right ventriculogram. The left-anterior oblique view demonstrates well the site and size of a VSD and its relation to the subarterial outlet. The presence of an overriding mitral valve or a common AV orifice should be demonstrated. Right ventriculograms normally demonstrate the relationship between arterial outlets and the presence of any obstructive lesion in the outflow tract.

Conclusion

In conclusion, DORV and its variants, which have a high incidence of associated cardiac malformations, can be diagnosed noninvasively by echocardiography. An initial plan of management can usually be provided by this procedure. The procedure includes catheterization and angiography, which are necessary in planning a definitive surgical procedure.

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Diagnostic Approach to Hypoplastic Right Heart and Pulmonary Atresia: Invasive and Noninvasive

GARY SHOLLER

Summary. Hypoplastic right heart continues to be a challenge because of its heterogenous anatomical substrate and physiological consequences. A combined echocardiographic and angiographic approach to management is presented, with the results in 39 patients (1984–1993) described. Survival has improved, and individualised surgical management has optimised medium-term outcome. Nevertheless, completed surgery still eludes at least one-third of patients.

Key words. Congenital—Heart disease—Pulmonary valve—Atresia

Introduction

Hypoplastic right heart syndrome, associated with pulmonary atresia or critical pulmonary stenosis, is a deceptively simple condition for which management has remained difficult and often frustrating. In this discussion of the diagnostic approach to hypoplastic right heart syndrome, I would like to present the strategies used in my Department at the Royal Alexandra Hospital for Children in Sydney. We use echocardiography as the primary diagnostic tool, supplemented by angiography in selected cases in which echocardiographic assessment does not provide sufficient data.

The term hypoplastic right heart incorporates hypoplasia of the right ventricle, which may involve, to a varying degree, the inflow and tricuspid portion, the trabecular region, and the right ventricular outflow tract. These patients usually have pulmonary valve atresia, but may also have critical pulmonary stenosis. The tricuspid valve abnormalities associated with this syndrome, which are also variable, include stenosis, dysplasia, and frequently incompetence when the right ventricular pressure is high. Coronary sinusoids may occur, particularly where there is significant right ventricular hypoplasia, and these communications between the right ventricular cavity and the coronary supply often prove troublesome in management, predisposing to ischaemia and infarction in some patients.

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Assessment and Management Before the Current Era

Before the current era, these patients presented as critically ill and unstable with severe cyanosis, requiring emergency cardiac catheterisation and angiography, and emergency surgery that involved either shunting or an attempt at reconstituting right ventricle-to-pulmonary artery continuity. The problems of poor right ventricular compliance in a decompressed ventricle were often not appreciated, and may well have contributed to the high mortality in this group.

During this time, the classification of Greenwold et al. [1] was largely utilised; this separated the so-called correctable type II ventricle from the uncorrectable type I ventricle, with subdivisions of the type I ventricles into those with and without a right ventricular outflow tract. It became clear that this classification was insufficient, and Goor et al. [2], followed by Bull et al. [3], developed a tripartite approach to the right ventricle. The results during this early era of management were poor, with mortality rates well over 50% for other than mild right heart hypoplasia.

The Current Era

The new era of management coincided with the availability of prostaglandin for patient stabilisation, the introduction of echocardiography, and improved and broadened surgical management options. Our current diagnostic approach primarily utilises echocardiography, with angiography to supplement this information where necessary. The diagnostic strategy is driven largely by the surgical management options available.

We have classified our patients in a manner similar to that of Laks and Billingsley [4]. This method divides the patients according to tricuspid valve size and development of the right ventricular outflow tract, and arbitrarily separates mild, moderate, and severe hypoplasia of the right ventricle (Table 1). Naturally, there is overlap. The size of the trabecular region is also taken into account.

In our Unit, the initial approach for those with mild right ventricular hypoplasia is either a one-stage, neonatal repair or repair preceded by an initial stabilising systemic-to-pulmonary-artery shunt. For those with moderate hypoplasia, management is individualised but generally involves an initial arterial shunt. Some patients may undergo complete neonatal repair. All those patients with severe right ventricular hypoplasia are palliated with a initial arterial shunt and managed with a view to ultimate cavopulmonary operation. The subsequent management approach is then individualised (Table 2).

TABLE 1. Classification of pulmonary atresia with intact ventricular septum

	Tricuspid valve	Right ventricular outflow tract
Mild hypoplasia	>2/3	Good
Moderate hypoplasia	1/3–2/3	Present
Severe hypoplasia	<1/3	Absent

Modified from Laks and Billingsley [4].

TABLE 2. Surgical management options

Valvotomy/primary neonatal repair
Arterial shunt
Balloon dilation pulmonary valve
Right Glenn/IVC → RV
Bidirectional Glenn
Fontan/cavopulmonary repair
Coronary management

IVC, Inferior vena cava; RV, right ventricle.

Noninvasive Assessment

Our key diagnostic tool is echocardiography. This technique now also extends prenatally to foetal studies, with diagnoses made as early as 17 or 18 weeks of gestation. In all studies, we utilise a tripartite approach for the evaluation of the right ventricle [5,6]. This includes examination of the tricuspid valve size, which is compared both with normal size and with the mitral valve as an internal standard. The trabecular region is examined for size and compared both with normal dimensions and against the patient's left ventricular length. Trabecular spaces are assessed by colour Doppler distribution in diastole, which, when present, often predicts improvements in right ventricular diastolic volume once the ventricle is decompressed. The right ventricular outflow tract and pulmonary valve are also carefully examined. We attempt to identify coronary artery anomalies, particularly by concentrating on the size of the proximal coronary arteries and the presence of coronary–right ventricular flow. Echocardiography also remains our key tool for follow-up evaluation.

Tricuspid incompetence is frequently of assistance in evaluating the degree of right ventricular hypertension, and colour Doppler is also helpful when determining the inflow area of the right ventricle (particularly with tricuspid stenosis). Where there is tricuspid valve stenosis, the annular dimensions may overestimate the inflow capability of the ventricle.

Invasive Assessment and Management

Angiography remains an important supplementary tool for patients initially palliated with an arterial shunt. We generally wait until the age of 6–8 weeks when the pulmonary vascular resistance has diminished and the patient has stabilised from neonatal palliation. The right ventricle is reviewed in a tripartite fashion, and the trabecular spaces are especially well defined. Angiography also remains, at this stage, an important means of defining coronary communications to the right ventricular cavity. In cases with critical pulmonary stenosis, we also perform balloon dilation of the pulmonary valve where appropriate to reduce the right ventricular pressure and improve compliance for subsequent attempts at repair. We have found it advantageous to perform this when the pulmonary vascular resistance has normalised to avoid the problems of augmented pulmonary regurgitation and significant congestive

TABLE 3. Hypoplastic right heart syndrome, 1984–1993

	n	Complete repair	Completed surgery	Nonrepair	
				Waiting	Deaths
Mild	20	17	1	0	2 (10%)
Moderate	10	6	2	2	0
Severe	9	0	1	6	2 (22%)
Totals	39	23	4	8	4 (10%)

cardiac failure that can occur in the neonatal period when pulmonary resistance is high.

Patient Outcome

During the past 10 years, utilising this approach we have seen 20 patients with mild right ventricular hypoplasia. In half these patients, a primary valvotomy was performed with no mortality. In 10 patients in whom the right ventricular cavity appeared somewhat smaller, a number of different approaches were used after an initial palliative shunt. These included balloon dilation with or without subsequent surgical valvotomy in 4 patients, surgical valvotomy in 3 patients, and a Fontan procedure for 1 patient who had extremely poor right ventricular function despite adequate chamber volume. Two patients in this group died, 1 from sepsis.

There were 10 patients (Table 3) with moderate right ventricular hypoplasia, of whom 2 had a primary repair with neonatal valvotomy and 8 had an arterial shunt. Of this group, subsequently 1 had balloon dilation and later surgical valvotomy, 3 had surgical valvotomy, and 2 patients had a classical right Glenn and closure of atrial septal defect allowing inferior vena caval blood to pass via the right ventricle to the left pulmonary artery. This has been an extremely effective procedure, with excellent clinical outcome for these patients. One patient has had a bidirectional Glenn shunt and one patient is awaiting his next procedure following initial palliation. There were no deaths in this group.

There have been nine patients (Table 3) with severe right ventricular hypoplasia, all of whom had initial palliative arterial shunts. Three subsequently had bidirectional Glenn shunts and one a Fontan procedure, while three patients are waiting for surgery and two have died following initial arterial shunts.

Overall, 23 of 39 patients have had complete repair, and 4 patients had their course of surgical treatment completed but did not achieve a "normal circulation." The mortality for the whole group was 10%.

Conclusions

In cases of hypoplastic right heart, we have found that improved patient stabilisation, combined echo and staged angiographic assessment, and individual surgical management based on a tripartite right ventricular analysis have dramatically improved outcome for patients with hypoplastic right heart syndrome. Complete repair or separation of circulation still eludes about one-third of patients, who represent our next management challenge.

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The Diagnostic Approach to Truncus Arteriosus: Medical Aspects

M.A. Ali Khan

Summary. Truncus arteriosus, a rare congenital anomaly, usually presents in severe congestive heart failure in the first few weeks of life. If untreated, mortality in the first year is 78% from congestive heart failure, intercurrent infections, or pulmonary vascular disease. The defect represents partial or total absence of the aorticopulmonary septum, that is, complete absence of fusion of the truncal swellings and the conal ridges that normally join to form the arterial valves and the distal infundibulum. The accepted classifications are those of Collett and Edwards (1949) and Van Praagh and Van Praagh (1965). The clinical picture and natural history of truncus arterious in infants and children are largely determined by the size of the pulmonary blood flow, pulmonary vascular resistance, any narrowing of the pulmonary arteries, or the degree of truncal valve regurgitation. Electrocardiograms and chest X-rays help in making a diagnosis with the clinical picture, but the echocardiogram gives a strong indication of truncus arteriosus. If in doubt, cardiac catheterization and angiocardiography may be necessary before any surgical correction. The prognosis is poor because of the early onset of intractible congestive heart failure, pulmonary edema, and progressive pulmonary vascular disease beginning around 6 months of age. Cardiac failure is managed aggressively with digoxin, diuretics, vasodilators, and angiotensin-converting enzyme (ACE) inhibitors. At present, total correction is performed after stabilizing the patient at the time of diagnosis or between 1 and 3 months of age. The most optimistic aspect of early correction in the truncus anomalies is related to the absence of pulmonary vascular disease and to the growth of the pulmonary arteries. Besides pulmonary vascular disease and significant truncal valve regurgitation, an interrupted aortic arch is the most significant factor contributing to surgical mortality. Coronary artery anomalies and repair at ages greater than 3–6 months, however, may also contribute to surgical mortality.

Key words. Truncus arteriosus—Embryology—Coronary arterial anatomy—Cardiac catheterization

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Introduction

Persistent truncus arteriosus is a rare condition [<1% of all congenital heart disease (CHD)] in which all three circulations—systemic, pulmonary, and coronary—arise from a single vessel leaving the base of the heart, through a single valve. The defect is usually fatal without treatment. Introduction of the valved conduit has made surgical correction of the anomaly feasible.

Embryology

The most likely explanation for truncus arteriosus is lack of development of the conotruncal ridges, which are responsible for conotruncal septation. Absence of the conus septum leaves a ventricular septal defect (VSD), of which the superior margin is almost invariably the overriding truncal valve. Inferiorly, the defect is bounded by two prongs of the trabecular septomarginalis. Deficiency of the aorticopulmonary septum combined with virtual absence of the subpulmonary infundibulum and partial or complete absence of pulmonary valve tissue results in truncus arteriosus. The degree of deficiency of the aorticopulmonary septum determines the variability of the origin of the pulmonary arteries.

Anatomical Classification

In 1949 Collett and Edwards [1] recognized four types on the basis of the anatomical origin of the pulmonary arteries (Table 1). In type I, the most common variety, a short common pulmonary trunk arises from the side of the truncus arteriosus and gives rise to both pulmonary arteries. In type II, the pulmonary arteries arise separately from the trunk, close to one another from the posterior aspect. In type III, they arise at some distance from one another. Type IV truncus is now considered to represent a form of pulmonary atresia with VSD.

TABLE 1. Classification of truncus arteriosus

Type I: Common trunk → MPA bifurcates
Type II: Branch PAs arise contiguously from common trunk
Type III: Branch PAs arise widely separated from common trunk
Type IV: Absence of PAs from common trunk; PAs from descending aorta

MPA, Main pulmonary artery; PA, pulmonary artery.
From [1], with permission.

TABLE 2. Van Praagh's classification of truncus arteriosus

Type A: VSD present
1. Partially formed aortopulmonary (A-P) septum; MPA segment present
2. Absent A-P septum; MPA segment absent
3. One branch of PA segment absent
4. Underdeveloped aortic arch with patent ductus arteriosus (PDA)
(Subtypes 1–4 can occur with type A or B)
Type B: VSD absent

VSD, Ventricular septal defect.
From [2], with permission.

TABLE 3. Types of truncus arteriosus

Collett and Edwards [1] (n = 93)		Van Praagh and Van Praagh [2] (n = 57)		Calder et al. [12] (n = 100)
Type	%	Type	%	%
Type I	48	Type A1	47	50
Type II	29	Type A2	28	21
		(Indefinite A1 or A2)		9
Type III	11	Type A3	2	8
Type IV	12	Type A4	23	12
Totals	100		100	100

In Van Praagh's classification [2] (Table 2), most truncus cases have a VSD and belong to group A; group B recognizes the existence of persistent truncus without a VSD. Group A is further subdivided into four types: A1 is the same as Collett and Edwards' type I; A2 is the same as Collett and Edwards' types II and III; A3 is the absence of one pulmonary artery; and A4 is an underdeveloped fourth arch and interrupted aortic arch with a ductus (Table 3). In 80%–90% of cases, the main or both pulmonary arteries arise from the common trunk.

Morphological Features

Truncus arteriosus is found almost exclusively with situs solitus and D-loop segmental anatomy. In the majority of cases, the right ventricular infundibulum is deficient as in tetralogy of Fallot.

The VSD in truncus arteriosus is generally large and results from either the absence or pronounced deficiency of the infundibular septum. It is present between the two limbs of the trabecular septomarginalis. These limbs form the anterior and inferior margins of the defects. The posterior margin of the defect is formed by the ventriculoinfundibular fold, the muscle mass that separates the truncal valve from the tricuspid valve. In two-thirds of cases, it is very well developed and the conduction system is apart from the defect. In one-third of cases, this muscle is thin and deficient; the septal defect can extend up to the tricuspid annulus, and the proximal conduction tissue is vulnerable. The superior margin of the defect is invariably made up of the truncal valve. There is complete absence of the infundibulum and its septum (subarterial defect). The VSD is very rarely small or restrictive.

The semilunar valve is tricuspid in 68% of patients, quadricuspid in 25%, bicuspid in 6%, and either pentacuspid or hexacuspid in 1%. The presence of four or more leaflets results from incorporation of pulmonary valve tissue. The semilunar valve is in fibrous continuity with the mitral valve in all patients but is continuous with the tricuspid valve in a minority. The biventricular origin of the truncus is observed in 80% of patients. In 15%, the truncal valve is committed entirely to the right ventricle; in 5% of patients, it is entirely left ventricular in origin. The anatomical cause of truncal valve insufficiency is variable and includes thickened, nodular dysplastic cusps, prolapse of unsupported cusps, or conjoined cusps containing a raphe, inequality of cusp size, minor commissural abnormalities, or annulus dilatation; more than 50% have truncal valve regurgitation. Truncal valve stenosis, when present, is usually associated with nodular and dysplastic cusps.

A right-aortic arch is more commonly associated with truncus, occurring in 25%–35% of patients. Hypoplasia of the arch with or without coarctation of the aorta occurs in 3% of patients. Interrupted aortic arch occurs relatively frequently (6%–21%) and is accompanied by ductal continuity of the descending aorta. In such cases, the ascending aorta is hypoplastic, arising from the anterior-right aspect of the trunk. The ductus arteriosus is absent in approximately half the patients with truncus; when it is present, it will remain patent postnatally in nearly two-thirds of such patients.

The pulmonary arteries most commonly arise from the left posterolateral aspect of the truncus, a small distance above the truncal valve. A short, common trunk (type I) is observed in 60% of the patients, while type II accounts for 30% and type III represents 10%. Unilateral complete absence of one pulmonary artery may be present in 16% (11/70). In 9 of 11 cases, the pulmonary artery was absent on the side of the aortic arch [in tetralogy of fallot (TOF) the pulmonary artery opposite the aortic arch is usually absent]. Occasionally, stenosis of the origin and hypoplasia of pulmonary arteries can occur (Table 4).

Knowledge of coronary arterial anatomy is important to the surgeon in truncus arteriosus; coronary ostia are quite frequently abnormally located. The anterior descending coronary artery is frequently small and is displaced. The conus branch of the right coronary artery is usually prominent and supplies the right ventricular outflow tract. The posterior descending coronary artery arises from the left circumflex in 27%. Anomalies of coronary ostial origin are common (43%). There may be a single coronary artery ostium. When two ostia exist, both may arise from the same truncal sinus. High ostial origin is common and may be slitlike and stenotic. Rarely, the left coronary artery may originate from the pulmonary trunk. The following two variations are the most important: (1) the left coronary artery may arise high in the sinus of Valsalva near the origin of the pulmonary artery and it can be injured during repair; and (2) the right coronary artery can give rise to an accessory anterior descending branch crossing the right ventricle where ventriculotomy is performed.

The location of the conduction tissue in truncus is also of surgical importance. The left bundle branch runs along the left ventricular septal subendocardium. The right bundle travels within the myocardium until it reaches the moderator band. In most instances in which the VSD is truly infundibular and the membranous septum is intact, the atrioventricular (AV) conduction tissue is distant from the rim of the defect. Atrial septal defect (ASD) is noted in 15% of patients, although a patent foramen ovale is quite common. A persistent left superior vena cava draining to the coronary sinus is present in 7%, and partial anomalous pulmonary venous drainage is present in 2% of cases.

Extracardiac anomalies are present in 25% of autopsy cases of truncus arteriosus, and include skeletal deformities, hydroureter, bowel malrotation, and multiple complex anomalies. The incidence of truncus arteriosus is high in DiGeorge syndrome.

TABLE 4. Pulmonary arteries in truncus arteriosus

Unilateral complete absence:	11/70 (16%)
No left pulmonary artery	7/11 (64%)
No right pulmonary artery	4/11 (36%)
Absent pulmonary artery on side of aortic arch	9/11 (82%)
Stenosis at origin of pulmonary arteries	5/70 (7%)

From [3], with permission.

Clinical Features

The clinical picture and natural history of truncus arteriosus in infants and children is largely determined by the size of the pulmonary blood flow. This, in turn, depends on the pulmonary vascular resistance or on any narrowing of the pulmonary arteries. If truncal valve insufficiency is severe, the signs and symptoms of heart failure may appear shortly after birth.

When the pulmonary blood flow is large, the volume overload on the heart is severe. Any coexisting insufficiency of the truncal valve will make matters worse because of regurgitation. Once the pulmonary vascular resistance has risen from one-third to one-half system levels, the Eisenmenger reaction becomes progressive. Sixty-eight percent of infants presenting early died before reaching 3 months of age.

From a hemodynamic point of view, cases of truncus can be considered as follows:

Type A: High pulmonary blood flow with low pulmonary vascular resistance. Severe congestive heart failure results in early infancy and is resistant to medical management. Cyanosis is often not noted.

Type B: Normal or only slightly increased pulmonary blood flow, commonly caused by increasing pulmonary vascular resistance. These patients do not have failure but are cyanosed on exertion.

Type C: Low pulmonary blood flow, which may be caused by ostial narrowing or progressive pulmonary vascular disease. Cyanosis in these cases is marked.

The usual presentation of truncus arteriosus is that of severe, intractable congestive heart failure (CHF) in the second month of life (Table 5). Failure to gain weight is a constant feature. The infant is severely tachypneic and sweaty, with minimal cyanosis of the lips. The peripheral pulses are bounding. The precordium is hyperactive; a loud ejection click and single second heart sound are common features. There is a loud ejection systolic murmur at the base. There is also a middiastolic apical rumble. Truncal regurgitation usually results in a high-pitched, early diastolic murmur best heard at the lower-left sternal border. A continuous murmur in the truncus is rare, indicating either stenosis at the origin of the pulmonary artery, which may result from previous banding, or aorticopulmonary runoff.

The following changes occur by the third year of life at the onset of pulmonary vascular disease: (1) the peripheral pulses become less bounding in the absence of truncal regurgitation; (2) the systolic murmur becomes softer, because total flow

TABLE 5. Physical findings in truncus arteriosus with increased pulmonary blood flow

Signs of congestive heart failure
Bounding pulses
Hyperactive precordium
Systolic thrill at left sternal border
Loud ejection click
Continuous murmur
Apical third heart sound
Middiastolic rumble
Pansystolic murmur, lower-left sternal border
Truncal regurgitation murmur
Loud, single second heart sound (S2)

through the truncal valve is reduced; (3) the apical middiastolic murmur becomes softer; and (4) the child becomes progressively more cyanosed.

Electrocardiography

Right-atrial hypertrophy is frequently present. Right-axis deviation and combined ventricular hypertrophy are seen most often. Patients with decreased pulmonary blood flow may exhibit right ventricular hypertrophy only. Prominent left ventricular forces and left-atrial enlargement are not uncommon.

Chest X-Ray

Cardiomegaly is frequently present at birth. A right-sided aortic arch is present in about one-third of the patients and when occurring in conjunction with increased pulmonary vascularity and cardiomegaly is highly suggestive of truncus arteriosus. Dilated truncal root and high origin of the left pulmonary artery are also seen.

Echocardiography

The use of two-dimensional echocardiography has greatly increased the ability to determine the cardiac anatomy in malformations of the conotruncus. Direct visualization of the origin of the pulmonary arteries using high parasternal short-axis views scanning superiorly from the semilunar valve usually can differentiate the three lesions: truncus arteriosus, tetralogy of Fallot, or pulmonary atresia with VSD. Parasternal long-axis views demonstrate a single semilunar valve, in continuity with the mitral valve, overriding a VSD. Subxiphoid views will demonstrate the origin of the pulmonary arteries from the common trunk, which is the echocardiographic sine qua non of truncus.

Cardiac Catheterization and Angiography

Cardiac catheterization and angiography are necessary for surgery for truncus arteriosus. Patients with truncus arteriosus and unilateral absence of a pulmonary artery may be hemodynamically operable if the pulmonary resistance, calculated in the usual manner, is as high as 20 units/m^2.

The data of Mair et al. [3] suggest that the hemodynamically most favorable patients are those with pulmonary resistance of less than 8 units/m^2. These patients will have a systemic arterial saturation of 88% or greater. Conversely, a systemic saturation of less than 85% in a patient with two pulmonary arteries and without a pulmonary artery band or pulmonary artery stenosis probably means the patient is inoperable. The cardiac anatomy should be classified with angiocardiography: (1) truncal root injection to demonstrate pulmonary arterial origin and branching, truncal valve morphology, regurgitation, and coronary artery morphology; (2) injection into the left ventricle to show ventricular size, the details of the VSD, and the relationship of the truncal valve to the ventricles; and (3) right ventricle injection if the echocardiogram has not delineated the anatomy. The most helpful views are hepatoclavicular projection for the truncal root injection and long axial oblique for the left ventricle injection.

Natural History

Keith et al. [4] reported a survival rate of approximately 22% beyond 1 year of age, but Nadas and Fyler [5] reported 30%. Death in infancy is most commonly secondary to intractable CHF. In patients who survive the first few years, death may occur from volume overload and cardiac decompensation, but it more frequently results from complications of severe pulmonary vascular disease and occasionally after endocarditis.

Treatment

Accurate diagnosis and definition of the anatomy by echocardiography and, rarely, cardiac catheterization are extremely important in proper management of truncus arteriosus (Table 6). Cardiac failure is managed by the use of digoxin, diuretics, vasodilators, and ACE inhibitors. At the present time, total surgical repair is done at 1–3 months of age.

In the original operation described by McGoon et al. [6], based on the experimental work of Rastelli et al. [7], continuity between the right ventricle and the pulmonary arteries was established by use of a conduit of a homograft aorta and aortic valve. In 1972, because of problems with calcification and secondary obstruction, this was switched to a Dacron conduit and Hancock graft with a porcine valve. The technique has been further modified in recent years with direct connection of pulmonary arteries to the right ventricle using a pericardial monocuspid valve, or a conduit without valve interposition.

The risks of surgical correction depend on a number of factors [8–11] (Table 7). Patients with severe truncal valve incompetence are clearly a relatively high-risk group. Previous thoracotomy adhesions inevitably make surgical exploration more tedious. Patients with a pulmonary vascular resistance (PVR) greater than 8 units/m^2 are at substantially greater risk than those with values less than this level. The most optimistic aspect of early correction in the truncus anomalies is related to the absence of pulmonary vascular disease and to the growth of the pulmonary arteries. Besides pulmonary vascular disease and significant truncal valve regurgitation, an interrupted aortic arch is the most significant factor contributing to surgical mortality. The other two important factors that contribute to mortality are coronary artery anomalies and age at repair greater than 100 days.

TABLE 6. Information required for (safe) repair of truncus arteriosus

Anatomical type of truncus arteriosus
Age and weight of patient
Pulmonary vascular resistance and PaO_2
Ventricular function
Truncal valve regurgitation
Truncal valve stenosis
Coronary artery anatomy
Pulmonary artery stenosis (native and postbanding)
Associated defects (cardiac and noncardiac)
Degree of congestive heart failure (CHF) and emaciation

TABLE 7. Surgical risk factors in truncus arteriosus

Severe truncal valve regurgitation
Interrupted aortic arch
Coronary artery anomalies
Age at repair >100 days
With no risk factors, 100% survival
With one or more risk factors, 63% survival

n = 63 patients, September 1986–December 1991.
From [11], with permission.

In conclusion, the factors to be considered for "safe" repair of truncus arteriosus include the age and weight of the patient, truncus type, PVR, coronary artery anatomy, pulmonary artery stenosis, truncal valve regurgitation, ventricular function, truncal valve stenosis, and associated defects such as interrupted aortic arch and DiGeorge syndrome.

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Transposition of the Great Arteries: Coronary Artery Anatomy

Richard Van Praagh and Maria G. Kiaffas

Summary. Eight different coronary arterial patterns were found by Mayer and his colleagues during open-heart surgical repair of 314 patients with D-transposition of the great arteries (D-TGA). The mortality rates following the arterial switch operation (ASO) are given for each coronary arterial pattern; the mean mortality rate was 5.5%, varying from 3% to 33%. Other noncoronary-related causes of death are summarized, and the developmental basis of the variations in the coronary artery anatomy in D-TGA is considered briefly.

Key words. Transposition of the great arteries—Coronary artery anomalies—Arterial switch operation

Introduction

The coronary arteries were the key to Jatene's [1] successful accomplishment of the arterial switch operation (ASO) for D-transposition of the great arteries (D-TGA), and they remain one of the most important aspects of this operation. It is for this reason that we discuss here the coronary artery anatomy in physiologically uncorrected (complete) D-TGA.

In terms of surgical anatomy of the coronary arteries in D-TGA and the relation of the various coronary artery patterns to survival following the ASO, we summarize the experience of our own surgical colleagues, recently published by Mayer et al. [2]. We also endeavor to supplement these data with relevant postmortem findings and with a consideration of what is known concerning the developmental basis of the variations in coronary artery anatomy in D-TGA.

Results

In a series of 314 surgically observed patients with D-TGA, our colleagues found 8 different coronary artery patterns (Fig. 1). The ASO was performed in 290 of these cases, and they reported the mortality rates following the ASO for these various coronary artery patterns as follow:

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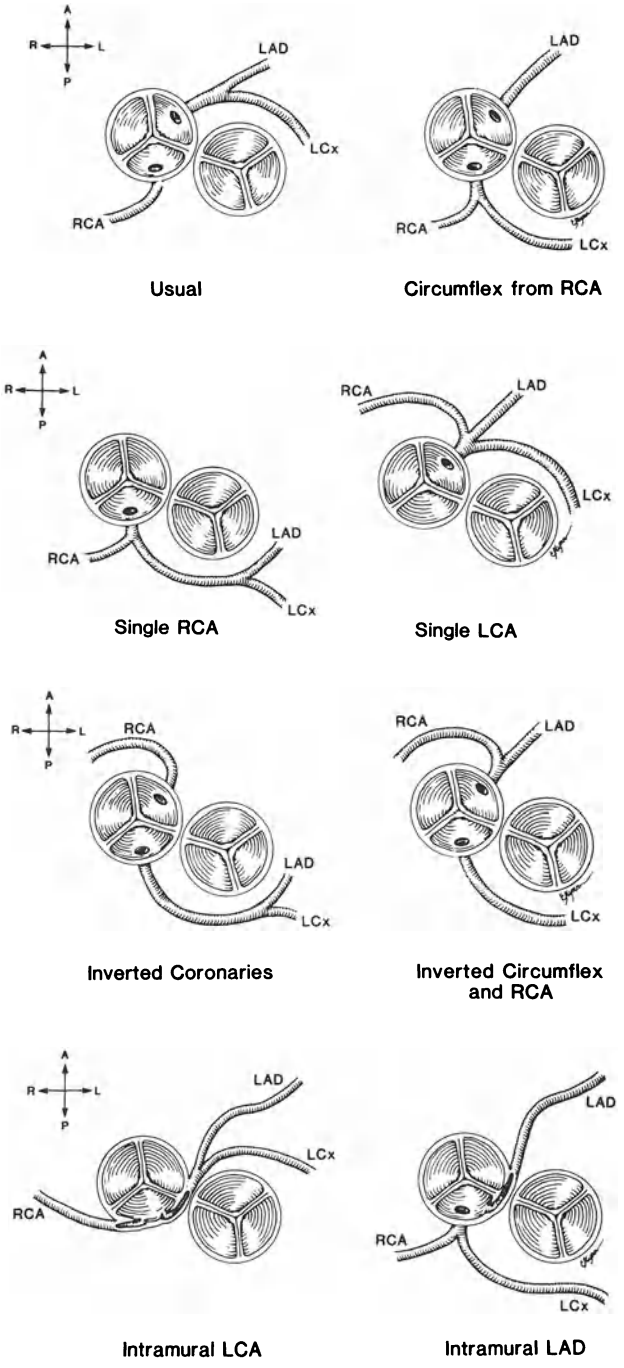

FIG. 1. Coronary artery patterns observed in 314 patients with D-transposition of the great arteries (D-TGA) undergoing surgical repair as described in text. *RCA*, Right coronary artery; *LCA*, left coronary artery; *LAD*, left anterior descending artery; *LCx*, left circumflex coronary artery. (From [2], with permission)

1. The Usual Pattern. As is usual in D-TGA, the left and anterior coronary ostium gave rise to the left anterior descending (LAD) coronary artery and the left circumflex (LCx) coronary artery, while the right and posterior coronary ostium gave origin to the right coronary artery (RCA) in 180 of 314 cases (57%). Mortality following the ASO was 5 of 180 (3%).
2. Left Circumflex from the Right. The LCx arose from the RCA in 66 of 314 cases (21%). The mortality following the ASO was 3 of 66 patients (4.5%).
3. "Single" Right Coronary Artery. A "single" RCA resulting from absence of the left coronary ostium was observed in 12 of 314 patients (4%). Mortality following the ASO was 4 of 12 (33%).
4. "Single" Left Coronary Artery. "Single" LCA resulting from absence of the right coronary ostium was noted in 7 of 314 cases (2%). Mortality following the ASO was 1 of 7 (14%).
5. Inverted Pattern. In the inverted coronary artery pattern, the left anterior coronary ostium gave rise to the RCA, while the right and posterior coronary ostium gave origin to the LAD and the LCx. This pattern was found in 8 of 314 patients (3%). Mortality following the ASO was 2 of 8 patients (25%).
6. Inverted Left Circumflex and Inverted Right. In the inverted left Cx and inverted RCA pattern, the LCx coronary artery arose from the right and posterior coronary ostium, and the RCA originated from the left and anterior coronary ostium; this pattern was found in 9 of 314 patients (3%). The mortality rate following the ASO was 0.
7. Intramural Left. An intramural LCA was found in 8 of 314 cases (3%); mortality following the ASO was 1 of 8 patients (12.5%). The intramural LCA arose from the right coronary sinus of Valsalva close to the septal commissure of the aortic valve (adjacent to the aortopulmonary septum), and then ran intramurally within the aortic wall between the great arteries to emerge anteriorly.
8. Intramural Left Anterior Descending. The pattern in which the intramural LAD arises from the right-posterior sinus of Valsalva and courses intramurally between the great arteries to emerge anteriorly was not found in any of the patients treated with the ASO. However, this pattern was observed in 1 of 24 patients (4%) treated with the Senning procedure.

Discussion

The overall mortality rate in this ASO series was 16 of 290 patients (5.5%). However, mortality varied from 3% to 33% in the various coronary pattern subsets.

Above the mean mortality rate of 5.5%, there were four coronary artery patterns:

1. Single RCA, with a mortality rate of 33% (4/12 patients)
2. Inverted coronary artery pattern, with a mortality rate of 25% (2 of 8 patients)
3. Single LCA, with a mortality rate of 14% (1/7 patients)
4. Intramural LCA, with a mortality rate of 12.5% (1 of 8 patients)

Although these four coronary artery patterns in D-TGA appear to constitute the higher risk patterns, the small number of cases within many of these subsets is noteworthy. We therefore suspect that it is too early to draw any firm conclusions.

This is also why we have refrained from doing statistical analysis: the numbers in each group are too small.

Also, the coronary artery patterns are not the only cause of morbidity and mortality in these patients following the ASO, even though problems related to the coronary arteries were by far the most important cause of death. For example, from 1983 to 1990, inclusive, the causes of death in 23 autopsied ASO patients were found to be the following [3]:

1. Coronary artery narrowing or occlusion: 13 patients (56.5%)
2. Congestive heart failure: 4 patients (17.4%)
3. Native aortic outflow tract narrowing: 3 patients (13%)
4. Intraoperative hemorrhage: 1 patient (4.3%)
5. Fibrosis from prior surgery: 1 case (4.3%)
6. Aspiration: 1 patient (4.3%)

Thus, 43% of patients died of noncoronary causes following the ASO.

Developmental Considerations

The aforementioned variations in coronary artery patterns associated with D-TGA appear to result from two developmental mechanisms: (1) variations in the anastomoses between the coronary buds sprouting from the aortic septal sinuses of Valsalva (the sinuses adjacent to the aorto-pulmonary septum) and the coronary angioblasts in the interventricular and atrio-ventricular sulci, and (2) anomalies of the coronary buds themselves (as opposed to the variable anastomoses just mentioned), resulting in absence of ostia and intramural coronaries. Absence of the left coronary ostium results in a "single" RCA. The quotation marks around single indicate that both coronary arteries are very largely present, the anomaly being absence of the coronary ostium and absence of the proximal portion of the main LCA between the absent LCA ostium and the rest of the LCA system.

Intramural coronary arteries appear to result from abnormal growth of the coronary artery buds themselves. It is also helpful to our understanding to appreciate that in the usual coronary artery pattern, the coronary artery buds from the aortic septal sinuses of Valsalva anastomose with the coronary angioblasts in the interventricular and atrioventricular sulci *opposite* from that which occurs when the great arteries are normally interrelated. These coronary bud–angioblast unions may be understood as spatial "marriages of convenience": buds unite with the closest convenient set of developing epicardial arteries. There is, however, considerable variation in these anastomoses, as the eight patterns listed previously indicate.

Typical D-TGA is a conal (infundibular) malformation [4], not really an anomaly of the great arteries per se. Variations in conal development in D-TGA result in quite a wide range of spatial semilunar interrelationships. Consequently, the spatial locations of the coronary ostia vary with the degree of dextral rotation of the aortic root. In D-TGA, the location of the aortic valve varies from just slightly to the right of the pulmonary valve and almost directly anterior to it, to an obliquely anterior and right-sided aortic location, to a side-by-side location of the aortic valve to the right of the pulmonary valve; infrequently, the aortic valve can be right sided and somewhat posterior to the pulmonary valve. This wide variability of coronary ostial locations,

which depends on the degree of dextral rotation at the semilunar valve level, appears to underlie much of the variability in coronary arterial patterns.

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Balloon Angioplasty of Pulmonary Artery Following Arterial Switch Operation for Complete Transposition of the Great Arteries

KAZUO MOMMA, TOSHIO NAKANISHI, and YASUHARU IMAI

Summary. Twenty-eight patients with transposition of the great arteries underwent 39 balloon angioplasty procedures after the arterial switch operation. The mean age at dilation was 4.5 years (range, 0.7–10 years). The mean interval between operation and balloon dilation was 3.6 years. The criterion of successful dilation was an increase of 50% or greater in the predilation diameter or a decrease of 50% or greater in the predilation pressure gradient. The success rate of balloon angioplasty for pulmonary artery stenosis was 51%. The interval between operation and dilation in the successful dilation group was significantly less than that in the unsuccessful dilation group. In 13 patients who underwent balloon angioplasty less than 3.5 years after operation, balloon dilation was successful in 92%. A balloon-to-artery ratio of more than 2.3 was necessary to dilate the stenotic segment. There were no deaths, but one pulmonary artery rupture, which did not require surgical intervention, occurred. Aneurysmal dilation of the pulmonary artery was observed in 3 patients. These data indicate that although the success rate of balloon angioplasty for pulmonary artery stenosis after the arterial switch operation is modest (50%), balloon angioplasty can be the first therapeutic choice owing to the low complication rate and the potential benefit of the procedure. The success rate can be high if angioplasty is performed less than 3.5 years after operation and a balloon of adequate size is used.

Key words. Balloon angioplasty—Pulmonary artery—Arterial switch operation—Complete transposition of the great arteries

Introduction

Following an atrial switch operation, the arterial switch operation has been widely accepted as the method of repair for complete transposition of the great arteries [1–4]. The surgical results of the arterial switch operation have improved, and excellent results, with immediate surgical mortality of less than 10%, have been achieved [5–9]. Several intermediate-term results of the arterial switch operation have been reported [10–13]. One problem that occurs in patients postoperatively is supravalvular and peripheral pulmonary artery stenosis [14,15]. The stenosis may be so severe that the

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right ventricular pressure may exceed the left ventricular pressure, necessitating reoperation [14,15]. Balloon dilatation of the stenotic pulmonary artery has been attempted in some studies with little success [16–18]. We have tried a rather aggressive catheter intervention to the postoperative pulmonary stenosis, and the results are reported here.

Materials and Methods

In 200 patients with transposition of the great arteries, cardiac catheterization and Doppler echocardiography were used for studies following the arterial switch operation. Significant supravalvular stenosis of the pulmonary artery with a pressure gradient of more than 20 mm Hg was present in 20% of the patients (Figs. 1 and 2). The time-course of the development of pulmonary stenosis after the arterial switch operation was studied by a Doppler echocardiographic examination; 437 such echocardiographic examinations were performed to measure the maximum velocity in the pulmonary artery in 200 patients after the arterial switch operation. The 45 patients who underwent surgical or catheter angioplasty for a stenotic pulmonary artery constituted the pulmonary stenosis group (PS group), and the rest constituted the non-PS group.

Balloon dilation was performed to relieve supravalvular pulmonary stenosis after the arterial switch operation for transposition of the great arteries in 28 patients (Figs. 3 and 4). A total of 39 stenotic lesions were dilated. Fifteen patients had an intact ventricular septum, and 13 had a significant ventricular septal defect. Twenty-one patients underwent a primary arterial switch operation, and 7 had initially undergone the Blalock–Taussig shunt and pulmonary artery banding and then underwent an arterial switch operation. Anterior translocation of the pulmonary trunk (the Lecompte maneuver) [2] was performed in all patients. A pantaloon-shaped patch ($n = 8$), two U-shaped patches ($n = 10$), and other patches of preserved bovine pericardium were used to close both coronary artery sites and to enlarge the neopulmonary root. The mean age at dilation was 4.5 $\pm$ 2.2 years, and the mean interval between operation and balloon dilation was 3.6 $\pm$ 1.8 years.

After standard premedication, vascular access was established percutaneously using femoral vessels. A catheter was advanced to measure right- and left-sided hemodynamic variables. Cardiac output was measured using a thermodilution method. A small catheter was placed in the descending aorta to monitor blood pressure. Angiograms were performed in the pulmonary artery and the right ventricle. The decision to undertake balloon angioplasty was made if angiography showed a narrow segment with a pressure gradient of more than 20 mm Hg.

Systolic (maximum) and diastolic (minimum) diameters of stenotic segments and the pulmonary annulus were measured using a 1-cm grid. The mean of the maximum and minimum values was used to represent pre- and postdilation diameters. The distensibility of the stenotic segment was assessed by percent change of the diameter in systole and diastole. An end-hole catheter was positioned past the stenosis in the pulmonary artery, and an exchange wire, 0.035-in. or 0.038-in., was passed distally as far as possible into the lungs. After removal of the catheter, the angioplasty catheter (Meditech [Boston Scientific Corporation, Watertown, MA, USA] or Mansfield [Boston Scientific Corporation, Watertown, MA, USA]) was introduced through a sheath. The initial balloon size was chosen to be 2 to 4 times the diameter of the

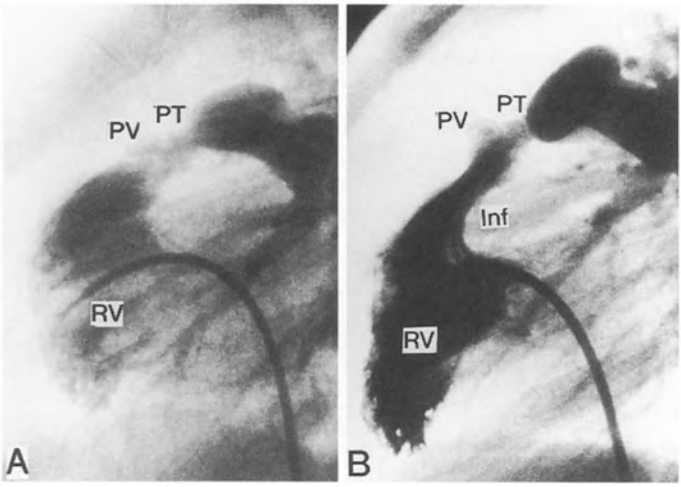

FIG. 1A,B. Progress of stenosis at the pulmonary trunk in a 1-year-old girl following arterial switch operation for complete transposition of great arteries at 1 month of age. **A** Mild stenosis, which progressed to severe stenosis 4 years later (**B**) with right ventricular pressure of 140 mm Hg. *Inf*, Infundibulum; *PT*, pulmonary trunk; *PV*, pulmonary valve; *RV*, right ventricle

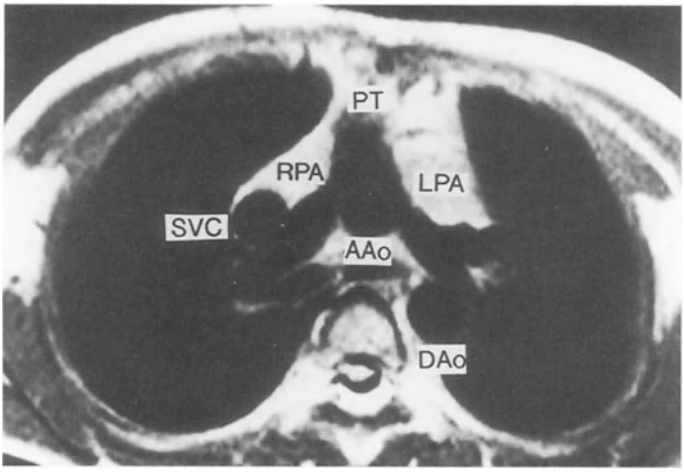

FIG. 2. Transverse magnetic resonance imaging (MRI) view of the stenotic pulmonary trunk and bifurcation in a 3-year-old boy who had surgical repair for transposition of the great arteries, ventricular septal defect, and coarctation of the aorta at 1 month of age. The pulmonary trunk and the bifurcation are compressed by the ascending aorta. *AAo*, Ascending aorta; *DAo*, descending aorta; *LPA*, left pulmonary artery; *PT*, pulmonary trunk; *RPA*, right pulmonary artery; *SVC*, superior vena cava

stenosed segment, not exceeding 1.7 times the pulmonary annulus diameter [16]. The full inflation ranged from 5 to 10 s, and three to four dilations were usually performed for each stenosis. After the dilations, the right and left hemodynamic variables were measured again, and angiography was performed in the pulmonary artery or the right ventricle.

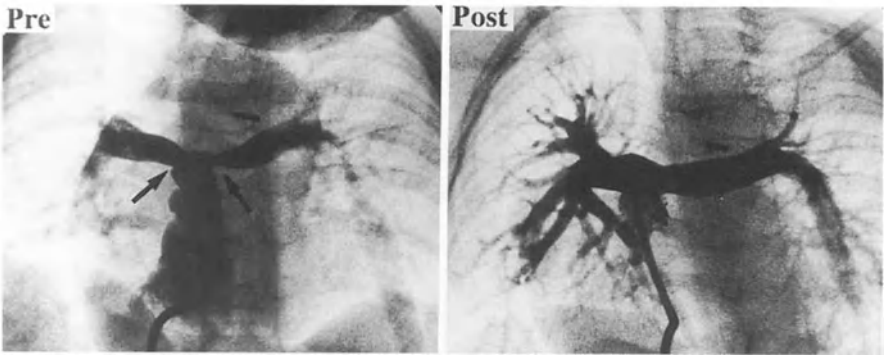

FIG. 3. Balloon angioplasty for stenotic right and left pulmonary arteries at the bifurcation in a 3-year-old boy after arterial switch operation. The postangioplasty angiogram (*right*) shows well-dilated pulmonary arteries

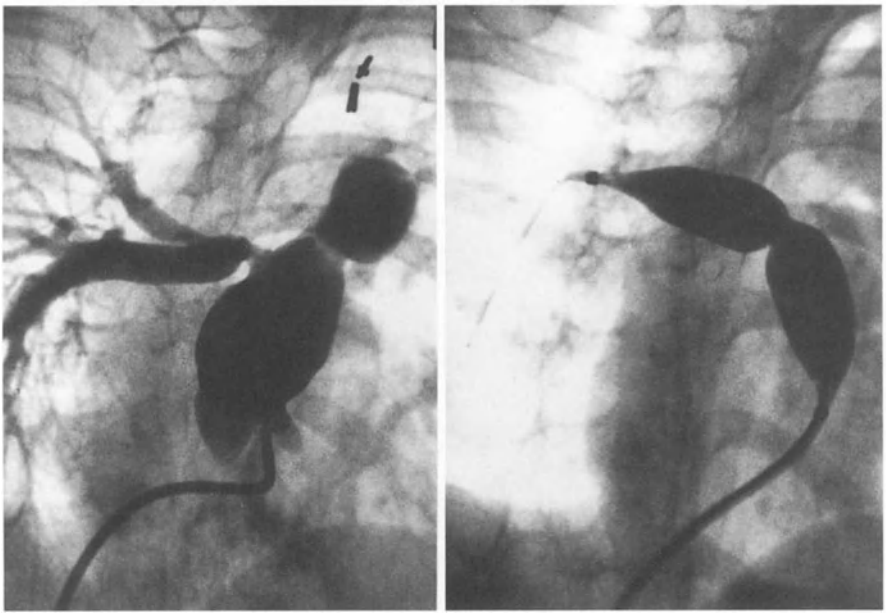

FIG. 4. Balloon angioplasty for stenotic right pulmonary artery at the bifurcation in a 5-year-old boy who had arterial switch operation for complete transposition of the great arteries in the neonatal period. The right ventricular pressure was increased to 135 mmHg, and balloon angioplasty was not effective

Successful angioplasty was defined arbitrarily as (1) an increase of more than 50% in the predilation diameter of the narrowed segment on angiography or (2) a decrease of more than 50% in the pressure gradient across the narrowed segment, using the criteria of Zeevi et al. [16].

Results

Pulmonary artery stenosis developed soon after operation and progressed further in the following years in 20% of the postoperative patients (PS group) (see Fig. 1). The maximum velocity in the pulmonary artery was accelerated to 2.4 m/s within 3 months after surgery in the PS group. It increased further, up to 4 m/s within 3–12 months after surgery, and remained at this high level 2–5 years after surgery. In the study performed at 2–5 years after surgery, the maximum velocity in the pulmonary artery was more than 3 m/s in 35 of 42 cases in the PS group and less than 3 m/s in 71 of 75 cases in the non-PS group.

Successful dilation was achieved in half the attempts (Figs. 3 and 5). Thirty-nine stenotic segments were dilated in 28 patients in total. The average increase in stenosis diameter was 59%, and the diameter increased 50% or more in 20 segments (51%). The right ventricular/aortic pressure ratio decreased 20% or more, so that it became less than 0.68 (clinical success) in 10 (50%) of these 20 patients.

Determination of success was assessed as follows: the interval after the arterial switch operation was the most significant determinant of the success rate. In 13

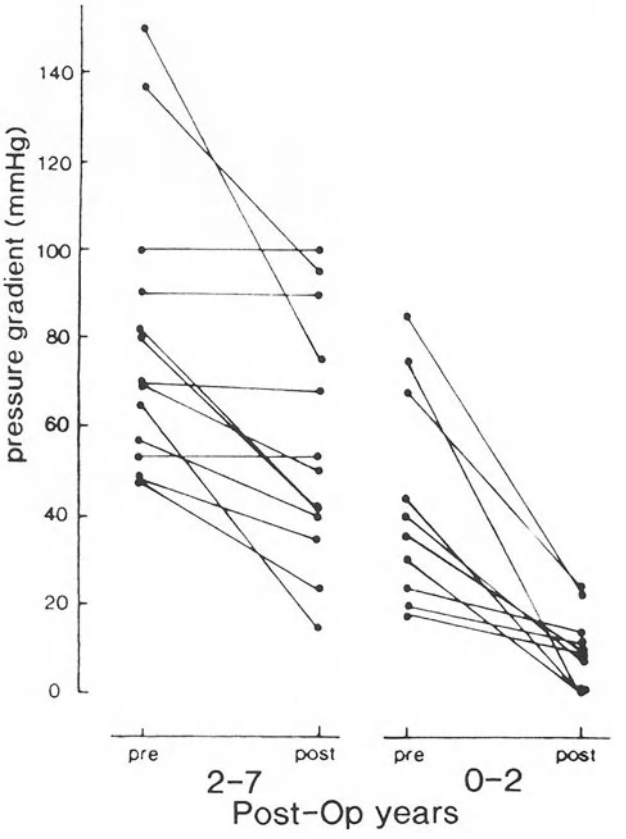

FIG. 5. Effects of balloon angioplasty for pulmonary stenosis following arterial switch operation for complete transposition were assessed by the pressure gradients across the stenotic segments. Pre- and postangioplasty pressure gradients show effective decreases in patients who had angioplasty within 2 years after operation

patients who underwent balloon angioplasty less than 3.5 years after the arterial switch operation, balloon dilation was successful in 92% (Fig. 5). The age at balloon angioplasty in the successful dilation group (2.4 years) was significantly younger than that in the group with unsuccessful dilation (5.4 years) (Figs. 5 and 6).

The balloon diameters ranged from 230% to 600% of the stenosis diameter in those patients with successful dilation. In the unsuccessful group, dilation was performed with the smaller balloon in one-third of the patients, but in the others it was done with a compatible balloon. Therefore the balloon size was only a partial determinant of success or failure of balloon angioplasty.

The pressure gradient before balloon angioplasty was compared in the successful and unsuccessful groups (Fig. 5). With the exception of two patients with very high pressure gradients of more than 100 mm Hg in the unsuccessful group, these two groups showed similar pressure gradients.

There were 16 stenoses at the anastomotic segment in the pulmonary trunk and 19 stenoses at the bifurcation. The success rate of balloon angioplasty for bifurcation stenosis was 74%, and was higher than that for pulmonary trunk stenosis (31%).

A close correlation was noticed between the angiographically assessed distensibility and the effectiveness of balloon dilation (Fig. 6). In patients in whom the percent change of the diameter in systole and diastole was more than 5%, balloon angioplasty was more effective than in patients in whom the value was less than 5%.

Complications were few, and there were no deaths. In one patient, the pulmonary artery ruptured at the bifurcation. Although the mediastinum widened immediately,

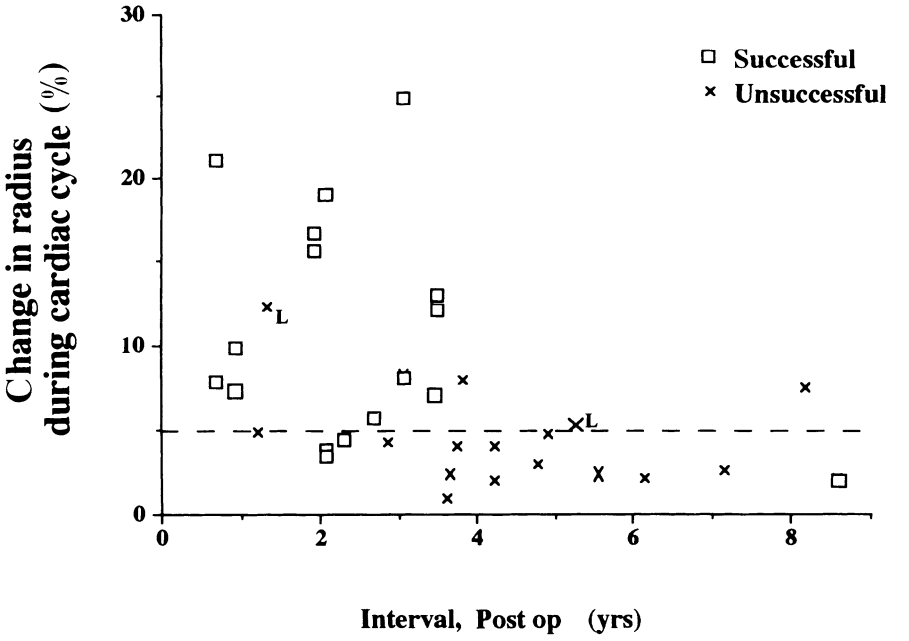

FIG. 6. Effects of balloon angioplasty analyzed as to postoperative interval and percent change in radius during a cardiac cycle. Successful cases (*squares*) are distributed at 1–3 years (postoperative interval) and have large changes in percent, more than 50%; unsuccessful cases are shown by *x*s

neither hypotension nor a decrease in hematocrit was observed, and the patient did not require surgical intervention. The pulmonary artery dilated aneurysmally in three patients, and an intimal tear was visible on a cineangiogram.

Discussion

Progress of Stenosis

Doppler echocardiography in this study revealed the early development of the supravalvular pulmonary artery stenosis. It develops within a few months after surgery and advances further in the following years. The progress of the stenosis can be assessed by Doppler echcardiography. The maximum velocity of more than 3 m/s in the pulmonary artery will be a good indicator for balloon pulmonary angioplasty.

Success Rate

We obtained a modest but definite success in the balloon angioplasty after arterial switch operation (ASO) for transposition of the great arteries (TGA). Early poor results reported from the Boston Children's Hospital [16] were analyzed as follows. They tried five patients, with only one success. The successful patient had balloon angioplasty 6 months after ASO with a balloon/artery ratio of 2.5. The other unsuccessful patients were treated either too late (5 years after ASO, case 4) or with too small a balloon with a balloon/artery diameter ratio of less than 2.4 (cases 1–3). Saxena et al. [17] reported no success in five patients. They used a smaller balloon with a diameter ratio of balloon/artery of less than 2.4 except in one trial. In this study, we showed that successful dilation was achieved with a larger balloon with a diameter ratio of more than 2.3.

Another factor determining the success rate was the interval between the surgery and balloon dilation [19,20]. We obtained successful dilation until 3.5 years after surgery; beyond that period, the balloon dilation was usually unsuccessful. The previous study showed clearly that the angiographic distensibility of the stenotic artery decreased yearly after surgery, and the angiographic vascular distensibility was closely correlated with the success rate of the balloon angioplasty [20]. Therefore, the angiographic distensibility in a diagnostic catheterization is predictive as to the success rate of the following balloon angioplasty.

Conclusion

Balloon angioplasty is feasible for the treatment of pulmonary stenosis following arterial switch operation for complete transposition of the great arteries. It will be successful if it is done within 3.5 years after surgery using a large balloon with a diameter ratio of more than 2.3.

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Pulmonary Atresia with Intact Ventricular Septum: Right Ventricular and Coronary Artery Anatomy

Richard Van Praagh, John Papagiannis, Chrysoula Hanioti, and Maria G. Kiaffas

Summary. In this series of 71 postmortem cases of pulmonary atresia with intact ventricular septum (PAt c̄ IVS), the PAt was valvar only in 85%, and valvar plus infundibular in 15%. The size of the tricuspid valve (TV) corresponded closely to that of the right ventricular (RV) sinus. The TV/mitral valve (MV) diameter ratio and RV/LV inlet length ratio expressed the degree of RV cavity smallness quantitatively. When the TV/MV diameter ratio was equal to or less than the median range (≤0.51–0.60), sinusoids were almost always present (90%). However, when this ratio was above the median range, sinusoids were infrequent (10%). More than half of the cases of PAt c̄ IVS and sinusoids had no significant coronary artery disease (58%); however, the other 42% did have various types of coronary abnormality. Coronary anomalies were present in 16% of cases of PAt c̄ IVS without sinusoids.

Key words. Pulmonary atresia with intact ventricular septum—Tricuspid valve—Right ventricle—Sinusoids—Coronary artery

Introduction

Pulmonary atresia with intact ventricular septum (PAt c̄ IVS) is an infrequent form of congenital heart disease that continues to pose a difficult therapeutic challenge. Of the 3038 cases of congenital heart disease currently recorded in the Cardiac Registry of the Pathology Department of the Children's Hospital in Boston, Massachusetts, USA, 86 (2.83%) had PAt c̄ IVS.

Do the findings of our congenital heart disease pathology registry really reflect what is happening in the community—in the "real" world? One might suspect a priori that such pathology data would be skewed in the direction of "badness" and would therefore be nonrepresentative. One might also object that ours is an institution-based study, not a community-based study, and that our hospital attracts "rare birds" from all over the world and hence our pathology data probably are not representative of what is really happening in the community.

Consequently, we compared our Cardiac Registry data (an institutional pathology database) with the findings of the New England Regional Infant Cardiac Program

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(NERICP) of Fyler and his colleagues [1]: Between 1969 and 1974 inclusive, there were 2251 liveborn infants born with congenital heart disease in the six New England states (USA), and PAt c̄ IVC was present in 75 (3.33%). There is no statistically significant difference between our pathology database as recorded in the Cardiac Registry and the findings of the NERICP ($P < 0.25$). It may perhaps be that the pathology data and the community-based liveborn infant data are not significantly different because the pathology data have been collected for a long time (1944–1994, i.e., 50 years) through all cardiac surgical eras (closed heart and open heart).

We were asked to focus our attention on the right ventricular (RV) and coronary artery anatomy associated with PAt and IVS. Typically, PAt c̄ IVS has a "peach-stone RV"—the RV resembling a peach from which the stone has been removed, having a small cavity and a thick wall. Other characteristic features include RV endocardial fibroelastosis (EFE); sinusoids between the RV cavity and the coronary arteries; coronary anomalies; anomalous muscle bundles of the RV; tricuspid valve anomalies; and a prominent eustachian valve of the inferior vena cava.

Thus, PAt c̄ IVS is much more than just a deficiency of pulmonary blood flow because of the coexistence of PAt with a characteristically small, curved, "comma-shaped" patent ductus arteriosus (PDA). In this duct-dependent lesion, the PDA is characteristically small and comma shaped because ductal size depends on flow in utero, which is largely (or only) left-to-right to the high-resistance lungs because of the coexistent pulmonary atresia, rather than right-to-left from the pulmonary artery to the descending thoracic aorta, which is normal. With PAt and IVS, because the left-to-right shunt is small (to the high-resistance lungs before birth), the PDA is small, long, and curved, and is often described as tortuous. Thus, the PDA on which the patient's life depends typically is disadvantageously small.

Although we currently focus most of our therapeutic efforts on restoring pulmonary blood flow toward normal, the problem posed by PAt c̄ IVS is much greater. Consequently, this request to investigate the RV and the coronary artery anatomy in this anomaly is most welcome.

Methods

A detailed study of the RV and coronary anatomy was recently carried out in 71 postmortem cases of PAt c̄ IVS.

Findings

PAt was found to be valvar (only) in 60/71 cases (85%), being both valvar and infundibular in 11 cases (15%). The size of the tricuspid valve (TV), when compared with age-matched and weight-matched controls, was found to accurately reflect the size of the RV sinus (inflow tract) into which the TV opened. The TV was nearly normal in size in only 2/71 cases (3%). The TV was hypoplastic but not dysplastic (a miniature) in 7 cases (10%). However, in the majority, the TV was found to be both hypoplastic and dysplastic (in 49/71 cases, 69%). Ebstein's anomaly was found in 7/71 patients (10%), with tricuspid regurgitation in 4 (6%) and tricuspid stenosis in 3 (4%). The TV was dysplastic and larger than normal in 6 patients (8%).

An investigation of the histopathology of the right ventricle (RV) was undertaken in 42 cases in which the histological slides of the RV were available and labeled; i.e., unlabeled slides were excluded. To summarize, myocardial hypertrophy (100%) and interstitial fibrosis (40%) were the commonest histopathological findings. Other abnormalities are presented in order of decreasing prevalence (Table 1).

TABLE 1. Salient right ventricular microscopic findings in PAt c̄ IVS

Findings	No. of cases (n = 42)	Percentage of series
Hypertrophy	42	100
Marked hypertrophy	19	45
Interstitial fibrosis	17	40
Combination of hypertrophy and marked hypertrophy	10	24
Perivascular fibrosis	6	14
Myocyte necrosis or degeneration (not infarct)	6	14
Prominent sinusoids	5	12
Infarcts, dating from approximately 12 h to 2 months	4	10
Endocardial changes: thickening, fibrosis, hemorrhage	4	10
Coronary artery changes (mural thickening, 1; medial elastosis, 2)	3	7
Calcification, intramyocardial	2	5
Endocardial fibroelastosis	2	5

Quantitation of RV Sinus Size

An effort was made to quantitate the size of the RV sinus in a way that potentially could be employed clinically, such as by short-axis two-dimensional echocardiography. The size of the TV was compared with the size of the patient's mitral valve (MV) by measuring the diamemters of the TV and the MV and calculating the TV/MV diameter ratio. In 19 normal control heart specimens, the TV/MV diameter ratio was never less than 0.9, but in PAt c̄ IVS, a TV/MV diameter <0.9 was found in 59/71 cases (83%). In PAt c̄ IVS, the median TV/MV diameter ratio was in the 0.51–0.60 range, the smallest ratio being in the 0.11–0.20 range and the largest >1.11.

Another clinically potentially relevant approach to the quantitation of RV volume in PAt c̄ IVS was to examine the ratio of the RV/LV inlet lengths, measured from the atrioventricular valve annulus to the ventricular apex. We speculate that this ratio could be measured in the parasternal long-axis view by two-dimensional echocardiography. The RV/LV inlet length ratio was ≤ 0.40 in none of the normal control hearts. However, in PAt c̄ IVS this RV/LV inlet length ratio was ≤ 0.40 in 28/71 patients (39%). In these PAt c̄ IVS cases, the median RV/LV inlet length fell in the 0.41–0.50 range, the smallest ratio being again in the 0.11–0.20 range and the largest ratio again greater than unity (>1.21).

Is the RV Cavity Size Related to the Presence or Absence of Sinusoids?

Sinusoids were found in 21/71 patients with PAt and IVS (30%). Sinusoids tended to be associated with smaller RV cavity sizes. When the RV cavity size was equal to or less than the median size (TV/MV ratio ≤ 0.51–0.60 range), sinusoids were almost always present (19/21 cases, 90%).

Assessing RV cavity size by means of the RV/LV inlet length ratio, when this ratio was equal to or less than the median range, i.e., the 0.41–0.50 range, sinusoids were present in 16/21 patients (76%). Conversely, when the TV/MV diameter ratio was greater than the median range (≥0.51–0.60), sinusoids were found in only 5/21 cases (24%).

What Is the Relationship Between Sinusoids and Coronary Arteriopathy?

In the 21 patients with sinusoids, the coronary arteries were found to be normal in 10 (48%) or were dilated only in 2 cases (10%). Thus, more than half the patients with sinusoids had no clinically significant arteriopathy (58%). However, 42% of these patients with sinusoids did have clinically important coronary artery changes:

1. Narrowing only in 1 (5%)
2. Coronary artery interruption in 2 (10%)
3. Atresia of the ostium of the right coronary artery (RCA) in 5 (24%)
4. Atresia of the ostium of the RCA plus stenosis of the left anterior descending (LAD) coronary artery in 1 patient (5%).

Perhaps surprisingly, the following coronary artery abnormalities were found in 8 cases of PAt c̄ IVS without sinusoids (8/50 patients, 16%):

1. Absent ostium of the RCA, resulting in a "single" left coronary artery in 2
2. Dilated RCA in 1
3. Dilated LAD in 1
4. Stenosis and dilatation of the LAD in 2
5. Accessory (third) coronary artery from the main pulmonary artery communicating with a conal branch in 1
6. Stenosis of the ostium of the RCA with dilatation of the LAD and of the posterior descending coronary artery in 1 patient.

Discussion

In PAt c̄ IVS, although the presence of pulmonary atresia (valvar, with or without infundibular) is of primary importance, the diagnostic and therapeutic challenge of these patients goes far beyond the presence of pulmonary outflow tract atresia. PAt c̄ IVS is much more than a hemodynamic derangement or rerouting of the circulation. As this study has endeavored to indicate, there are also major problems involving the tricuspid valve, the RV sinus, and the coronary arteries.

It should perhaps be mentioned that the problem with PAt c̄ IVS is not that one or more parts of the RV are missing. Except when tricuspid atresia coexists (when the tricuspid valve and the RV sinus are atretic), all four component parts of the RV are present, although often small. The four component parts of the definitive RV [1] are (1) the atrioventricular (AV) canal or junctional component, (2) the RV sinus (the pump and hence the sine qua non of the RV), (3) the septal and moderator band portion (proximal conus), and (4) the parietal band portion (distal conus).

As was pointed out by Davignon and his colleagues [2], the competence of the TV appears to determine the size of the RV: when there is no tricuspid regurgitation (TR), the RV does little or no flow work, only pressure work, and thus is small chambered

and thick walled. Endocardial sclerosis or frank endocardial fibroelastosis (EFE) is typical and is believed to represent a secondary, global, subendocardial myocardial infarction related to the inability of the coronaries to perfuse the subendocardial layer when RV intracavitary pressures remain very elevated (above coronary artery perfusion pressure, mainly in diastole). As has been noted, sinusoids are commonest in the small RV cavity group.

When there is some TR, the RV is larger (and sinusoids are fewer) because the RV can do flow work, retrogradely. When TR is severe, the RV cavity can be larger than normal.

Cases of PAt c̄ IVS with a congenitally unguarded tricuspid orifice (absence of tricuspid valve leaflets), with or without Uhl's disease (parchment RV), were not represented in this series.

Speculation

We suggest that time should be introduced into the therapeutic "equation" as follows. The anatomic findings strongly suggest that, rather than doing a tetralogy of Fallot type of RV outflow tract reconstruction as the initial surgical procedure in the neonatal period, one should open up the RV outflow tract with a guidewire or with laser pulmonary valvulectomy, followed by balloon dilatation of the perforated pulmonary valve. Then, we speculate, one should allow time to "Brock"—to remodel—the RV and the RV outflow tract. Later, by 1–2 years of age, one could operate to do a pulmonary outflow tract reconstruction. In other words, we think that a tetralogy of Fallot type of pulmonary outflow tract reconstruction in the neonatal period involves far too much RV myocardial outflow tract excision, and therefore that this reconstruction should be deferred until after RV remodeling has occurred. Following RV remodeling, patency of the RV outflow tract can then be accomplished with relatively minor trauma to the RV.

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The Anatomy of the Ventricles and of the Atrioventricular Valves in Single Ventricle

Richard Van Praagh

Summary. Absence of the right ventricular (RV) sinus (inflow tract) results in single left ventricle (LV) with an infundibular outlet chamber (74%). Absence of the LV sinus results in single RV (26%). Single RV almost always has no infundibular outlet chamber. Both single LV and single RV can have double-inlet (with two atrioventricular [AV] valves) or common-inlet (with a common AV valve). Tricuspid atresia and mitral atresia are customarily diagnosed as such, and hence are not included here. Application of the morphologic method at the ventricular level is the key to the diagnostic understanding of single ventricle. The connection of the AV valve(s), as in univentricular AV connection, is not an accurate method of diagnosing single LV or single RV. Single LV may not have a univentricular AV connection: the Lambert heart. Univentricular AV connection with an RV usually is not a single RV: a small LV typically is also present.

Key words. Single ventricle—Double-inlet ventricle—Atrioventricular valves

Introduction

Anatomic Types of Single Ventricle

There are two anatomic types of single ventricle: (1) absence of the morphologically right ventricular (RV) sinus, resulting in a single morphologically left ventricle (LV) with infundibular outlet chamber (IOC); and (2) absence of the LV sinus, resulting in a single RV [1,2].

With a single LV, there typically is a double-inlet LV, i.e., both atrioventricular (AV) valves open entirely or predominantly into the single LV, or a common-inlet LV, in which a common AV valve opens entirely or predominantly into the LV. However, with single LV, i.e., absence of the RV sinus, it is possible for the tricuspid valve (TV) to open not into the single LV but predominantly or entirely into the infundibulum outlet chamber; this is known as the Lambert heart [3]. Similarly, a double-inlet RV or common-inlet RV usually is *not* associated with single RV; typically, a small LV is present.

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Definition

In view of the foregoing, it has been appreciated for the past 30 years that the old definition of single ventricle in terms of the AV valve(s), i.e., double inlet or common inlet, is not satisfactory. The only accurate method of defining and diagnosing the presence of a single ventricle (absence of the RV sinus or absence of the LV sinus) is in terms of the morphology of the ventricular myocardium, i.e., the morphologic method.

Nonetheless, because of the older definition of single ventricle in terms of the AV valves (i.e., double-inlet or common-inlet ventricle), it is now customary to exclude tricuspid atresia and mitral atresia from the category of single ventricle; tricuspid atresia and mitral atresia are diagnosed as such rather than being regarded as forms of single ventricle.

From the standpoint of morphologic anatomy, tricuspid atresia is in fact closely related to single LV because the RV sinus (and the tricuspid valve) typically are atretic (nearly absent); however, mitral atresia usually has a small LV sinus, and if a ventricular septal defect (VSD) coexists, the LV sinus can be approximately normal in size even though mitral atresia coexists.

Consequently, at the present time single ventricle is defined and diagnosed primarily in terms of the morphologic anatomy of the ventricular myocardium, rather than in terms of the alignments and connections of the AV valves which, however, are very important. Ventricular myocardial anatomy and the status of the AV valves are in fact two different variables involving different cardiac segments. The AV valves represent the AV canal or junctional segment, while the ventricular myocardium represents the ventricular loop.

What is common ventricle? Although this exists, it is very rare, i.e., an RV free wall and LV free wall are present but are not separated because of the absence or extreme underdevelopment of the interventricular septum. Common atrioventricular canal with a huge AV septal defect is not regarded as a common ventricle because a definite subdividing remnant of the muscular ventricular septum is present. In common ventricle, the RV and the LV are in common, not separated by any muscular ventricular septum. We have not seen a single case of this very rare entity during the past 30 years at the Boston Children's Hospital, although I did see two cases at the Mayo Clinic before this time.

There are other senses in which the term common ventricle has been used. Dr. Jesse E. Edwards used to use this designation as essentially synonymous with single ventricle. Dr. Maurice Lev used to employ the term common ventricle to mean a ventricle that received both AV valves or a common AV valve and from which both great arteries originated directly; i.e., such a ventricle was common to both inlet valves and to both outlet valves. By contrast, Lev used the term single ventricle when both AV valves or a common AV valve entered one ventricle, and when one (or rarely both) great arteries originated from the infundibular outlet chamber.

Applying the morphologic method that was introduced by Lev, we subsequently found that Lev's common ventricle was a single RV, without an infundibular outlet chamber, while Lev's (and Taussig's and Abbott's) single ventricle with an outlet chamber was a single LV with an infundibular outlet chamber. Thus, Lev's and Edward's usages of single and common ventricle, as summarized here, reflect a premorphologic understanding that antedates the morphologic anatomic "deciphering" of the ventricular myocardium. The sense of common ventricle that I used

previously reflects the later morphologic anatomic understanding of the ventricular myocardium: RV and LV are in common because of absence of the ventricular septum.

Henceforth, this presentation is concerned with single ventricle, i.e., single LV and single RV, common ventricle being excluded.

Material and Methods

Of the 3038 autopsied cases of congenital heart disease currently enrolled in the Cardiac Registry of the Children's Hospital in Boston, Massachusetts (USA), single ventricle was present in 92 cases (3.03%).

Because one wishes to know whether this statistic is meaningful, i.e., whether the findings of our pathology database accurately reflect what is really happening in the community, the aforementioned pathology findings were compared with the findings of the New England Regional Infant Cardiac Program (NERICP), a large epidemiological study based on the six New England states in which all liveborn infants with congenital heart disease were enrolled. The prevalence of single ventricle in the NERICP between 1969 and 1974 was 58/2381 liveborn infants (2.44%). No statistically significant difference was found between the findings of the pathology database and the findings of the community-based liveborn infant series ($P < 0.25$, not significant).

Findings

Absence of the RV sinus, i.e., single LV, was found in 68/92 cases (73.9%), and absence of the LV sinus, i.e., single RV, was observed in 24/92 cases (26.1%) in our cardiac pathology series.

Regarding anomalies of the AV valves, in 47 postmortem cases of single LV with IOC, a common AV valve was present in 14 (30%), tricuspid regurgitation was found in 11 (23%), and tricuspid stenosis was present in 5 (11%). (Tricuspid and mitral atresia were excluded by definition.)

Discussion

This study confirms that single LV (absence of the RV sinus) is much commoner than is single RV (absence of the LV sinus): 74% versus 26%, respectively.

Both phylogenetically and ontogenetically, this may be understood as follows. The morphologically right ventricle (RV) is a comparatively "recent" evolutionary development, appearing only about 180 million years ago during the Ordovician and upper Devonian periods. By contrast, the morphologically left ventricle (LV) is at least 500 million years old, dating from the appearance of vertebrates as ancient fish. Neither fish nor amphibia have an RV, but higher reptiles (such as crocodiles and alligators), birds, and mammals normally do. The RV appears in incomplete form, with a persisting interventricular foramen (ventricular septal defect), in lower reptiles such as turtles and tortoises; in higher reptiles, however, the ventricular septum is intact.

Hence, from the phylogenetic standpoint the RV is only about 36% as old as the LV (180 vs 500 million years). This appears to be one of the reasons why the RV is much more prone to malformation than is the LV, which is the ancient systemic pump of the

vertebrates. The RV is a relatively recently evolved adaptation to air-breathing and land-living conditions of the amniotic vertebrates, which includes all animals with an amniotic sac. The evolution of the amniotic sac was the key to breeding on land—which amphibia cannot do—and was thus basic to successful colonization of the land. The amniotes then evolved into reptiles, birds (feathered reptiles), and mammals (furry or hairy reptiles).

So too, in ontogeny (embryology), the development of the RV sinus normally lags behind that of the LV sinus. Both the LV sinus and the RV sinus begin to develop during horizon X (20–22 days following ovulation), but the LV sinus develops faster than does the RV sinus. By horizon XVIII (36–38 days), however, the development of the RV sinus normally has caught up with that of the LV sinus. Thus, the phylogenetically and ontogenetically late-developing RV sinus is definitely more prone to malformation than is the LV sinus, as the findings of this study exemplify.

Absence of the RV sinus (single LV) appears to represent an arrest of normal development at the stage before the development of the RV sinus, i.e., at approximately the horizon 11 stage (22–24 days of age). In contrast, absence of the LV sinus (single RV) does not resemble any normal stage in cardiac phylogeny or ontogeny. In this sense, single RV may be regarded as a malformation of the embryonic heart rather than as an arrest at a normal developmental stage.

As indicated in the Introduction, the old definition of single ventricle in terms of the atrioventricular valvar connections (double-inlet ventricle, common-inlet ventricle, i.e., univentricular AV connection) is now understood to be unsatisfactory because of the existence of many well-documented exceptions: (1) the Lambert heart with single LV and infundibular outlet chamber in which the tricuspid valve opens predominantly or entirely into the infundibular outlet chamber; and (2) the fact that double-inlet RV usually is *not* a single RV, a small LV sinus typically being present. Consequently, in the interests of accuracy, single ventricle now must be defined and diagnosed in terms of the ventricular myocardial morphology.

However, univentricular AV connection (i.e., double-inlet and common-inlet ventricle) is a very important diagnosis per se. Double-inlet or common-inlet ventricle means that from the physiologic and surgical standpoints the patient has only one functional ventricle. Nonetheless, to avoid confusion, we do our utmost to make diagnosis anatomically accurate, this being a generally accepted principle.

The status of the AV valves and the status of the ventricles are two different variables. Both are important. They represent two different cardiac segments: the AV canal or junction, and the ventricular loop. For example, double-inlet RV may or may not be associated with a single RV. Usually a small LV sinus is present, but occasionally the LV sinus is absent and a single (unpaired) RV is present.

Does single ventricle result from a huge ventricular septal defect (VSD)? Briefly, no. The usual problem is not a huge VSD, but the absence of one ventricular sinus: absence of the RV sinus (body, inflow tract, or pumping portion), resulting in a single (unpaired) LV with an infundibular outlet chamber, or absence of the LV sinus, resulting in a single (unpaired) RV, typically without an infundibular outlet chamber. However, the very rare common ventricle is indeed a huge VSD, i.e., virtual absence of the muscular interventricular septum.

Why is an infundibular outlet chamber typically associated with single LV, but only rarely with a single RV [2]? When the RV sinus is absent, the ventricular septal remnant moves toward the side of the absent RV sinus—to the right with a D-loop or to the left with an L-loop—just as the mediastinum shifts toward the side of a small or

absent lung. This movement of the ventricular septum toward the side of the absent RV makes the ventricular septal remnant (well-developed on the LV sinus side, but very shallow and undeveloped on the side of the absent RV sinus) underlie the infundibular or conal septum. This approximation of the ventricular septum to the conal septum produces a narrowing of the inlet, the bulboventricular foramen, that leads from the single LV into the infundibular outlet chamber. This narrowing, in turn, is what produces the appearance of a chamber. Indeed, the approximation of the ventricular septum to the infundibular septum can be so close as to produce a stenotically small foramen or even an absent foramen—spontaneous closure of the bulboventricular foramen [2]. However, this narrowing or delimitation between the single LV and the infundibular outlet chamber may be widely patent and associated with no pressure gradient. Even so, the infundibular outlet portion of the heart resembles a chamber because there is some narrowing leading into the infundibulum at the level of the bulboventricular foramen (i.e., the opening between the bulbus or conus or infundibulum and the ventricle of the bulboventricular loop that gives rise to the LV sinus).

By contrast, when the LV sinus is small or absent, the muscular ventricular septum moves toward the side of the small or absent LV, far away from beneath the conal septum. The ventricular septum moves leftward and posteriorly with a D-loop or rightward and posteriorly with an L-loop. Although the infundibulum is present beneath the great arteries, it no longer looks like an infundibular outlet *chamber* because there is no inlet constriction. As in tetralogy of Fallot, there must be some inlet narrowing for the infundibulum to resemble a chamber. The presence or absence of an infundibular outlet chamber is diagnostically helpful because the presence of such a chamber typically is associated with a single LV [1] but only rarely with a single RV [2].

Is the infundibular outlet chamber a rudimentary RV? No. The infundibulum is not a ventricular sinus. The infundibulum is the outflow tract of both ventricular sinuses. Normally, the infundibulum is incorporated mostly into the RV, but also to a small extent into the LV. In other words, the infundibulum is normally fused mostly with the RV sinus and only to a small extent with the LV sinus. Abnormally, however, the infundibulum can straddle the ventricular septum to virtually any degree, this being known as straddling conus. In double-outlet LV and in anatomically corrected malposition of the great arteries, the conus (infundibulum) can be located predominantly above the LV and fused with the LV sinus. Thus, the conus is the outlet portion of both ventricles, not a rudimentary RV.

With single LV and infundibular outlet chamber, is it accurate to say that because there are two chambers in the ventricular mass, that a single ventricle is not present, accurately speaking? No, this is wrong. Normally, below the level of the atria there are three chambers (not two): the LV sinus, the RV sinus, and the infundibulum. When there are only two chambers, this suggests that one of the chambers is missing. Morphologic analysis of the myocardium reveals that the RV sinus is absent. So, the simplistic assertion that because there are two chambers in the ventricular mass and therefore that single ventricle is not present—is incorrect for the aforementioned three reasons: (1) there are three chambers below the atria normally, not two; (2) myocardial morphologic analysis reveals absence of the RV sinus; and (3) the infundibular outlet chamber is not a rudimentary RV, but the outlet portion of both ventricles. One cannot decide accurately whether or not single ventricle, i.e., one ventricular sinus, is present by simply counting chambers. Instead, one must identify

what the chambers are morphologically. Only then will you know whether two ventricular sinuses are present, resulting in a biventricular heart, or only one ventricular sinus is present, resulting in a univentricular heart (single ventricle).

Is the term univentricular heart better than the term single ventricle? No. These terms are synonymous and therefore, by definition, one cannot be better than the other. *Single ventricle* is the old plain English term. *Univentricular heart* is a recently coined latinate synonym. Although unnecessary, *univentricular heart* will probably be seen as a terminologic enrichment. Synonyms (such as *conus* and *infundibulum*) provide variety; this is not bad. But what is bad is the assertion that one synonym is better than the other, because this is absurd; by definition, synonyms are equivalent.

Is the term double-inlet LV better than the term single LV? No, each is acceptable, when accurate. These designations are not synonyms. Single LV may have a double-inlet, common inlet, or single inlet (the Lambert heart). As mentioned, the status of the AV valves and the status of the ventricular myocardium are two different variables and both are important. These are different diagnoses, both of which must be made. For example, you have to know whether a single LV has a double inlet (separate AV valves), common inlet (a common AV valve in the setting of a common AV canal), or single inlet (with the tricuspid valve opening predominantly or entirely into the infundibular outlet chamber).

The Controversy

Why has there been so much controversy over single ventricle? This has occurred at least in part because the old definition of single ventricle in terms of the connection of the AV valve(s), a univentricular AV connection, proved to be wrong on analysis of the morphology of the ventricular myocardium. It is difficult when a basic definition turns out to be wrong. If not all influential investigators realize that the old definition is wrong, and if some decide to try to defend and save the old definition, then controversy becomes inevitable. This is essentially what happened. In the interests of understanding, I include a personal perspective at this point.

When I was a Fellow at the Mayo Clinic in Rochester, Minnesota (USA), working in the cardiac catheterization and angiocardiography laboratory in 1959–1960, my chief, Dr. Jeremy Swan, assigned me the research project of figuring out what single ventricle really is, with the hope that this understanding would lead to more accurate diagnosis and safer cardiac surgery. At that time, if a single ventricle was incised at cardiac surgery—assuming that the patient had two ventricles—the almost invariable result was death of the patient. So the stakes were high. In my previous training in pediatric pathology, my teacher, Dr. John M. Craig, had told me about the work of Dr. Maurice Lev of Chicago, referring particularly to Lev's morphologic method for identifying the various cardiac chambers in congenital heart disease. I thought that perhaps this morphologic method might clarify the anatomic basis of single ventricle. So at night I worked in the Pathology Department at the Mayo Clinic. Unfortunately, Dr. Jesse E. Edwards had recently left Rochester and had gone to Minneapolis/St. Paul, Minnesota.

I gradually realized we had a problem: we had a number of cases that satisified the old definition of single ventricle, with both AV valves or a common AV valve opening entirely or predominantly into one ventricle, but in which morphologic anatomic analysis disclosed not only the presence of a large RV (with double-inlet or common-inlet RV) but also a small LV sinus. What should we do with these cases? Should we

include them in our study of single ventricle (because they satisfied the then generally accepted definition of single ventricle), or should we exclude them (because two ventricular sinuses—a large RV and a diminutive LV—were present)? We did not know what to do. My colleagues Dr. Patrick Ongley and Dr. Jeremy Swan decided that one of them (it was Dr. Swan) and I would take the train to Chicago to consult with Dr. Maurice Lev about this problem. Following a fascinating weekend of examining heart specimens and discussing them, it was agreed by all of us that such cases should be excluded from our study of single ventricle, because two ventricular sinuses (not just one) were definitely present. So that is what we did, and why.

At the time, I did not clearly realize that the old definition of single ventricle was unsatisfactory and illogical. Instead, we gave primary diagnostic emphasis to the morphologic method [1]. We hoped that subsequent investigators would do the same thing, but they did not. They made the mistake that we very nearly made. They accepted the old definition of single ventricle (double inlet and common inlet), giving primacy to this old definition rather than to the myocardial morphology. They soon confronted the same problem that we had encountered. They tried to solve this problem in a different way, by renaming things. One could say, for example, that if an AV valve opens less than 50% into a chamber, such a chamber is no longer a ventricle, but a *trabeculated pouch* or an *outlet chamber*. Apart from being arbitrary, this approach is also nonmorphologic: trabeculated pouch and outlet chamber have no specific morphologic anatomic meanings. The advantage of this approach is that one can disguise the fact that a second small ventricular sinus is present and hence one can say that such a heart is univentricular, by one's own arbitrary redefinition of a ventricle. (Parenthetically, I should indicate that we have never believed in such nominal or semantic solutions of anatomic problems.)

Another approach that preserves the old definition of single ventricle is to rename it *primitive ventricle*. Again, the problem with this attempted semantic solution is that primitive ventricle has no specific morphologic anatomic meaning. Is it a "primitive" LV, or a "primitive" RV, or is it a "primitive" LV + RV? The main proponents of the primitive ventricle approach thought, at the time, that the ventricular myocardial morphology was of secondary importance.

So, what looked like terminology wars from the outside has really been a struggle between the new morphologic anatomic approach to understanding single ventricle and the old definition of single ventricle in terms of AV valve connections. When the proponents of primitive ventricle and univentricular heart finally adopted double-inlet LV and double-inlet RV, the latter was a major improvement because it signaled that they had accepted the importance of ventricular myocardial morphologic analysis.

Other important repercussions of the single ventricle debate, however, remain poorly understood. For example, another approach that accepts the old definition of single ventricle (univentricular AV connection) and morphologic myocardial analysis is to say that single ventricle really does not exist. In single LV with infundibular outlet chamber, one can say that the coarse trabeculations down toward the apex of the infundibular outlet chamber really are a few trabeculations of the RV sinus. Although plausible, this is wrong. It is normal for a few coarse trabeculations to be found in front of the septal and moderator bands. It becomes important to understand that the real RV sinus is located *behind* (posterior and inferior to) the septal and moderator bands, as double-chambered RV illustrates so clearly. So, single LV with IOC certainly does exist. However, double-inlet LV can coexist with a small RV sinus posterior and inferior to the septal and moderator bands.

The rest of the "single ventricle does not exist" argument is that in double-inlet or common-inlet RV with absence of the LV sinus, the LV sinus is really present but was just missed, not found. This too, while plausible, is wrong, we think. Multiple careful transmural sections looking for a tiny LV definitely can be negative: no LV sinus is an accurate anatomic observation, not a careless mistake.

If one believes that single ventricle does not exist, this then leads to the dominant LV and dominant RV interpretation. This view is an improvement because it designates the morphologic identity of the large ventricle, but it is suboptimal in that it ignores whether a second small ventricular sinus is present. We think that a completely morphologic approach is preferable: one should know whether a second small ventricular sinus is present, and if present, its morphologic anatomic identity.

The tripartite concept of a ventricle is another anatomic error that arose from the single ventricle debate. This view holds that the RV consists of an inlet, a trabecular zone, and an outlet. The inlet is essentially identical with the RV sinus. The RV inlet, in this (we believe) erroneous view, is the ventricular myocardium embraced by the tensor apparatus of the tricuspid valve. Some proponents of this view used to say that in what is now agreed to be double-inlet LV, all the myocardium embraced by the tricuspid valve's chordae tendineae and papillary muscles is RV myocardium. No one, to my knowledge, believes this any more.

We think that accurately speaking there are two components that make up the RV inlet: (1) the AV canal or junction, the part that is absent or malformed in common AV canal, and (2) the RV sinus, the muscular pumping portion that is the sine qua non of the RV.

In the erroneous tripartite concept, the second compartment of the RV is the trabecular zone. This term comes from renaming the septal band plus the moderator band the *trabecula septomarginalis* (Tandler's old term for the moderator band), which was later anglicized to septomarginal trabeculation. Unfortunately, the septal band is a large smooth band of muscle; it is not trabeculated at all, but the RV sinus is.

We see nothing wrong with the old English names *septal band* and *moderator band* and thus have not advocated changing them. The septal and moderator bands, and their adjacent free-wall myocardium anteriorly, constitute for us the third component of the RV.

In the tripartite concept, the outlet part of the RV, the third component, lies above a horizontal line passing through the papillary muscle of the conus. Our fourth component is the conal septum, which proceeds outward into the free (or parietal) wall as the parietal band. Our dissenting colleagues' outlet component is more conceptual than anatomic; it does not begin at the top of the septal band, as our does. Instead, the bottom of their outlet component is an imaginary line that passes below the top of the septal band and runs horizontally through the papillary muscle of the conus (the muscle of Lancisi). This is not where the ventricular septum comes apart in congenital heart disease.

Briefly, then, the tripartite concept of a ventricle is an erroneous spin-off of the single ventricle debate. This concept divides the RV into three pie-shaped conceptual pieces. We think that there are four main components to the RV: (1) the AV canal, (2) the RV sinus, (3) the septal and moderator band (proximal conus), and (4) the parietal band (distal conus). These four components are anatomically accurate because this is how the RV comes apart in congenital heart disease. The quadripartite concept of the ventricles, because it is anatomically accurate, is helpful in the understanding of why ventricular septal defects are located where they are [4].

Is tricuspid atresia a form of single ventricle? Tricuspid atresia is very closely related to single LV with infundibular outlet chamber. However, as it has been customary to exclude tricuspid and mitral atresia from the category of single ventricle because of the old definition of single ventricle (double inlet and common inlet), we see no reason why this long-standing convention must be changed. Also, we think that there is also a difference between atresia and absence of the RV sinus. In tricuspid atresia, there usually is also atresia of the RV sinus. However, occasionally a diminutive RV sinus coexists with tricuspid atresia. In single LV, the RV sinus really is absent, insofar as we are able to tell. Consequently, the ventricular septum is displaced further to the right and anteriorly in a ventricular D-loop, or further to the left and anteriorly in a ventricular L-loop, permitting the right atrium to drain directly into the LV.

We think that identical entities should be classified together but that similar entities should not. Consequently, we have always supported calling tricuspid atresia by this well-established name, rather than introducing yet another unnecessary and long synonym such as "univentricular heart of left ventricular type with absent right atrioventricular connection." Nonetheless, we agree that the "small RV" that typically is associated with tricuspid atresia is composed entirely, or almost entirely, of the infundibulum. In tricuspid atresia, the "small RV" is the infundibular outlet chamber. Hence, in terms of morphologic anatomy, many cases of tricuspid atresia consist of single LV with infundibular outlet chamber and atresia of the tricuspid valve and RV sinus. Typical tricuspid atresia and typical single LV thus are very closely related entities that we still classify separately because of their differences.

Is mitral atresia a form of single ventricle? No. A small LV sinus is virtually always present. If a relatively large ventricular septal defect coexists, then the LV can be of good size, approaching normal. Our dissenting colleagues used to lump tricuspid and mitral atresia together with double-inlet and common-inlet ventricle under the rubric of univentricular heart (single ventricle), but I believe they have now reverted to the separate classification of tricuspid and mitral atresia.

Our views and terminology have changed very little over the past 30 years. There are now few real differences between our views and those of our colleagues. However, the single ventricle debate has cast a long shadow, as indicated heretofore. Apart from a few insiders, considerable confusion remains widespread concerning single ventricle. The purpose of this discussion is to help dispel some of the confusion and misunderstanding concerning this subject and to indicate that, to a very considerable degree, a consensus has at last been reached.

This discussion has been made as impersonal as possible because my desire is to clarify confusion with a factual approach, not to do battle with anyone. We have high regard for our dissenting colleagues. We think that the basic mistake they made was to believe the old premorphologic definition of single ventricle, i.e., double-inlet and common-inlet ventricle. This was a mistake that we could easily have made ourselves. We were saved from this error by Dr. Maurice Lev and his morphologic method.

Conclusions

1. In terms of morphologic anatomy, there are two anatomic types of single ventricle: (1) single LV (absence of the RV sinus) and (2) single RV (absence of the LV sinus).

2. Common ventricle (absence of the muscular ventricular septum, thereby placing the RV and LV sinuses in common) does exist, but is very rare. In terms of morphologic anatomy, common ventricle is a biventricular heart (both LV and RV sinuses are present), even though the ventricular sinuses are not separated by a ventricular septum. Functionally, common ventricle has only one ventricular chamber, composed of RV and LV sinuses in common.

3. Single ventricle can have a double inlet, common inlet, or single inlet. "Single LV" and "double-inlet LV" thus are not satisfactory synonyms, because single LV can also have a common-inlet LV (a common AV valve) or a single-inlet LV (as in the Lambert heart, in which the tricuspid valve opens predominantly or entirely into the infundibular outlet chamber).

4. The old premorphologic definition of single ventricle, i.e., double-inlet ventricle and common-inlet ventricle, has been found by morphologic anatomical analysis to be unsatisfactory. Also known as "univentricular atrioventricular connection," this old premorphologic definition of single ventricle is now understood to have numerous exceptions: e.g., double-inlet RV usually is not a single RV, a small LV sinus typically being present; and single LV may not have a univentricular atrioventricular connection, as in the Lambert heart in which the tricuspid valve opens predominantly or entirely into the infundibular outlet chamber.

5. Double-inlet ventricle, common-inlet ventricle, and other forms of univentricular atrioventricular connection are all important diagnoses per se, even though they are unsatisfactory criteria for the diagnosis of single ventricle.

6. Single ventricle can only be diagnosed accurately by applying the morphologic method to the ventricular myocardium, not by the connections of the atrioventricular valves. In congenital heart disease, each variable should be defined and diagnosed primarily in terms of itself. For example, the status of the ventricular myocardium (is one ventricular sinus absent?) can only be determined by examination of the ventricular myocardium, not by examination of the connections of the atrioventricular valves, important as the latter unquestionably are. The ventricular sinuses and the atrioventricular valves are two different variables. In congenital heart disease, one variable (such as the status of the ventricular myocardium) cannot be defined and diagnosed primarily in terms of another variable (such as the status of the atrioventricular valves). This is what the old definition of single ventricle erroneously attempted to do: to diagnose one variable (the presence or absence of single ventricle) primarily in terms of a different variable (the status of the connections of the atrioventricular valves). This old definition of single ventricle involves an elementary error in logic (defining one variable primarily in terms of another variable). This is why the old definition of single ventricle in terms of the connections of the atrioventricular valves often does not work: the old definition is logically flawed.

7. Consequently, the presence or absence of single ventricle cannot be predicted with a high degree of accuracy by the connections of the atrioventricular valves, because one variable (the presence of one or two ventricular sinuses) cannot be diagnosed with a high degree of accuracy by a different variable (the connections of the atrioventricular valves), as double-inlet right ventricle and the Lambert heart indicate.

8. The key to the diagnostic understanding of single ventricle is the application of the myocardial morphologic method to the ventricular part of the heart. We should stop trying to diagnose single ventricle in terms of the connections of the atrioventric-

ular valves. Instead, we should regard these connections as additional, independent, and important diagnoses. We should appreciate that one cannot "solve" the diagnostic problem of single ventricle by changing names. "Univentricular heart" and "single ventricle" are synonyms; neither is better, nor worse, than the other, by definition. "Double-inlet ventricle," "common-inlet ventricle," and "univentricular atrioventricular connection" are all expressions of the old unsatisfactory premorphologic definition of single ventricle. In addition to the connections of the atrioventricular valves, which are important, it is also necessary to understand the ventricular myocardial morphology.

9. In association with single left ventricle, the infundibular outlet chamber is not a rudimentary right ventricle. The infundibulum is the infundibulum, period; the right ventricular sinus typically is absent. The sinus, body, inflow tract, or pumping portion is the essence—the sine qua non—of the right ventricle and the left ventricle. If the RV sinus is absent, there is no right-ventricular pump, as in the commonest form of single ventricle, i.e., single LV (74%). When the LV sinus is absent, there is no left ventricular pump, as in the less common form of single ventricle, i.e., single RV (26%). The infundibulum or conus is the outflow tract of *both* ventricular sinuses. The infundibulum is not an intrinsic, inseparable part of the RV only. The infundibulum can be related mostly or even entirely to the left ventricle, as in double-outlet left ventricle and in anatomically corrected malposition of the great arteries. Thus, the infundibular outlet chamber is just that. It is not a rudimentary right ventricle, nor is it a rudimentary left ventricle. In terms of myocardial morphologic anatomy (again we must emphasize the importance of using the morphologic method), the infundibular outlet chamber is just that.

By calling the infundibular outlet chamber a rudimentary right ventricle, some have sought to suggest that the concept of single left ventricle is wrong. How can one talk about a *single* left ventricle if a rudimentary right ventricle is also present? We think that the correct answer to this question is: A "rudimentary right ventricle" is *not* present. The right ventricular sinus is not rudimentary, i.e., hypoplastic or dysplastic; the right ventricular sinus is absent. Only the infundibulum—the conal connector—is present, the right ventricular sinus, the sine qua non of the RV, being absent. It is noteworthy that rudimentary right ventricle is not a morphologically accurate designation, but infundibular outlet chamber is.

10. Application of the morphologic method to single ventricle has greatly clarified and simplified our understanding of this form of congenital heart disease. In terms of accurate morphologic anatomy, it is now clear that (1) absence of the right ventricular sinus results in a single (unpaired) left ventricular sinus with an infundibular outlet chamber (74%), and (2) absence of the left ventricular sinus results in a single (unpaired) right ventricular sinus (25%).

Thus, understanding the pathological anatomy of single ventricle has at last become clear and simple.

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Ventricular Septation and Fontan Procedures for the Univentricular Heart

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Summary. Indications and results were compared between transatrial ventricular septation (S) and Fontan (F) procedures for univentricular heart (UVH). Of 21 patients who had ventricular septation, 19 had a UVH of the left ventricular (LV) type. Twenty patients had two atrioventricular (AV) valves, and 1 had a common AV valve. Fifteen patients had previous pulmonary artery banding (PAB), and subaortic stenosis (SAS) mainly caused by a narrow outlet foramen required enlargement in 9. The smallest ventricular volume was 172% of normal. Of 92 patients who had the Fontan procedure, 31 were of the LV type and the remaining 61 of the right ventricular (RV) type. Forty-nine patients had one or more systemic-to-pulmonary artery (SP) shunts for pulmonary stenosis (PS), and 7 had PAB previously. AV valve regurgitation was repaired simultaneously in 37 cases. The preoperative mean pulmonary artery (PA) pressure (29 ± 15 vs 15 ± 4 mmHg) and pulmonary vascular resistance (Rp, 3.2 ± 2.3 vs 1.7 ± 0.8 Wood units) were significantly higher in the septation group than in the Fontan group. There was no significant difference in postoperative cardiac index (S, 3.1 ± 1.2; F, 2.8 ± 0.7), and operative mortality and long-term survival (S, 89.5% vs F, 88.6% at 8 years) of the two groups were comparable. Risk factors for death after the procedures were high LV systolic and end-diastolic pressures and ventricular hypertrophy for the septation, and high Rp, low PaO_2, pulmonary venous anomaly, and longer aortic cross-clamp time for the Fontan procedure. In conclusion, patients with UVH of LV type without significant PS and AV valve atresia or stenosis can be good candidates for ventricular septation. After PAB as a palliative procedure, an early septation procedure is recommended because reduction in ventricular volume and concentric hypertrophy caused by progression of SAS may ensue. Patients with UVH of RV type and of LV type can be candidates for Fontan procedure, and should undergo early and often repeated palliative procedures that prevent pulmonary hypertensive changes (tight PAB in patients without PS) and that promote development of the pulmonary vascular bed (adequate SP shunt for PS or after initial PAB).

Key words. Univentricular heart—Surgical treatment—Ventricular septation—Fontan operation—Single ventricle

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Introduction

Surgical treatment of the heart with a univentricular atrioventricular connection has been a challenge to cardiac surgeons. The ventricular septation procedure for the univentricular heart was first reported by McGoon and associates in 1956 using a transventricular approach [1]. The same operation was performed successfully by Arai and associates [2] at our institution in 1971. Detailed studies of the conduction system in the univentricular heart were reported by Anderson and colleagues in 1974 [3]. Consequently, a transatrial approach for ventricular septation was suggested by Doty and associates [4] in 1979. On the other hand, applying the concept of total right ventricular bypass developed by Fontan and colleagues [5], a modified Fontan procedure for repair for univentricular hearts was reported by Yacoub and Radley-Smith [6] in 1976. Although results were improved, they were not entirely satisfactory [7–9].

Our experience with the modified Fontan procedure since 1977 and transatrial ventricular septation since 1986 for treatment of the univentricular heart [10–12] is reviewed here with particular reference to the indications and perioperative management.

Materials and Methods

A total of 113 patients with univentricular heart underwent definitive surgery at our department between January 1977 and September 1994. Of those, 21 patients had the transatrial ventricular septation procedure (septation group) and 92 patients had a Fontan-type procedure (Fontan group) at a mean age of 6.5 and 10.2 years, respectively. The male-to-female ratio was approximately 2 to 1 (Table 1). Intracardiac anatomy, associated lesions, prevalence of palliative surgery, catheterization data before and after the operation, and surgical results were compared in these two groups.

Catheterization Study

Standard right and left heart catheterization and cineangiography were performed before the operation and approximately 1 month after operation. End-diastolic ventricular volume was calculated for the morphological left ventricle using the area–length method [13] and for the morphological right ventricle using Simpson's method as modified by Graham et al. [14]. The volume was expressed as percentage of expected volume of the normal left ventricle or right ventricle calculated from the patient's body surface area using a formula reported by Nakazawa et al. [15].

TABLE 1. Demographic data

Factor	All	Septation	Fontan
No. of patients	113	21	92
Age at operation (years)	9.5 ± 5.3	6.5 ± 3.5	10.2 ± 5.4
Gender (male/female)	78/35	15/6	63/29

TABLE 2. Additional procedures

Procedure	Septation (n = 21)	Fontan (n = 92)
Enlargement of outlet foramen/SAS resection	9	1
Damus–Kaye–Stansel anastomosis	0	1
AV valve plasty	4	37
Partition of common AV valve	1	0
Resection of supravalvular tricuspid stenosis	2	0
Arterial switch	2	0
RV–PA conduit	1	0
SVC–PA anastomosis for contralateral SVC	0	15
Angioplasty for PA branch stenosis	0	15
LA–PV anastomosis for anomalous PV return	0	2
Enlargement of PV orifice	0	3
AV node modification	0	2
Surgical ablation of AV accessory pathway	1	0

SAS, Subaortic stenosis; AV, atrioventricular; RV, right ventricle; PA, pulmonary artery; SVC, superior vena cava; LA, left atrium; PV, pulmonary vein.

Surgical Technique

Ventricular Septation Procedure

The details of the septation procedure have been reported previously [10,11]. The standard surgical technique of the ventricular septation procedure in a univentricular heart with previous pulmonary artery banding includes transatrial partition of the ventricle, removal of the pulmonary artery band with end-to-end reconstruction, and enlargement of the outlet foramen. The septation patch is sutured in place with multiple pledgeted-mattress sutures. In patients with {S,L,L} anatomy, several sutures were placed from within the outlet chamber at the posterocranial margin of the outlet foramen to avoid injury to the anteriorly positioned conduction system. At the apical portion of the partition, coarse trabeculations and papillary muscles usually make anchoring the patch difficult; therefore, a few transmural pledgeted-mattress sutures were used. Nine patients had enlargement of the outlet foramen or resection of a subaortic stenosis, four had atrioventricular (AV) valve plasty, and one required partition of a common AV valve. In two patients with a right-sided outlet chamber from which the aorta originated, a simultaneous arterial switch procedure was performed. Other additional procedures are listed in Table 2.

Modified Fontan Procedure

The standard Fontan procedure consists of oblique partition of the atrium, diverting the AV valves and coronary sinus into the functional left atrium through a figure-of-7 atriotomy in the trabeculated portion of the atrium, and wide direct anastomosis between the cranial aspect of the atriotomy and the divided pulmonary artery with an incision extended into the right pulmonary artery. Additional procedures varied according to the diverse associated lesions (see Table 2).

Statistical Analysis

The unpaired t-test or chi-square test with Yates's correction was used to detect differences between the two groups. The paired t-test was used for comparisons

between preoperative and postoperative values. The Cox–Mantel test was employed for comparison of the actuarial survival analysis.

Results

Intracardiac Anatomy and Associated Lesions

Of 21 patients in the septation group, 19 were of the left ventricular (LV) type and 2 were of indeterminate type. In the Fontan group, 61 patients (66%) were of right ventricular (RV) type and 32 were of LV type. The most common segmental anatomy in the septation group was {S,L,L}; however, ventricular septation was feasible in other anatomy combined with the arterial switch procedure when necessary (Table 4).

In the Fontan group, heterotaxia was present in one-third (Table 3). In the septation group, the incidence of subaortic stenosis was high, 9 of 21 patients, and 3 of these patients also had coarctation of the aorta that had been repaired previously. On the other hand, pulmonary stenosis or atresia was common in the Fontan group. In the septation group, 20 patients had two atrioventricular (AV) valves and 1 had a common AV valve. AV valve anomaly was more common in patients in the Fontan group; however, AV valve regurgitation was quite common in both groups (Table 5).

TABLE 3. Visceral situs

Visceral situs	Septation	Fontan
Solitus	21	53
Inversus	0	9
Asplenia	0	20
Polysplenia	0	9

TABLE 4. Segmental anatomy in the septation group

Segmental anatomy	Number of patients in the septation group
{S,L,L}	15
{S,D,D}	3
{S,D,N}	2
{S,L,D}	1

TABLE 5. Cardiac anatomy

	Septation (n = 21)	Fontan (n = 92)
Ventricular morphology		
Left ventricular type	19 (90%)	31 (37%)
Right ventricular type	0	61 (66%)
Indeterminate	2 (10%)	0 (0%)
AV valve morphology		
Two AV valves	18 (86%)	47 (51%)
Common AV valve	1 (5%)	31 (34%)
Right-sided AV valve atresia	0	6 (7%)
Left-sided AV valve atresia	0	7 (8%)
AV valve regurgitation	11 (52%)	41 (45%)
Pulmonary stenosis/atresia	5 (24%)*	84 (91%)
Subaortic stenosis	9 (43%)	2 (2%)

AV, Atrio-ventricular; *, mainly subvalvular.

Previous Palliative Surgery

In the septation group, 17 patients had a total of 22 previous surgical procedures (Table 6). Most commonly, 13 patients, 3 of whom also had repair of coarctation, had pulmonary artery banding. Two patients had a Blalock–Taussig shunt after placement of the pulmonary artery band to increase ventricular volume.

In the Fontan group, approximately two-thirds of the patients had one or more previous surgeries, most commonly a systemic-to-pulmonary artery shunt operation to stimulate growth of the pulmonary vascular bed. Eight patients with increased pulmonary blood flow, 2 of whom had concomitant repair of coarctation, had pulmonary artery banding. One patient with severe subaortic stenosis and a hypoplastic ascending aorta had the Norwood procedure.

Preoperative Hemodynamic Status

The septation group had a larger pulmonary-to-systemic flow ratio (Qp/Qs) and higher pulmonary artery pressures and resistance (Table 7). Nine patients (43%) in the septation group had pulmonary vascular resistance exceeding 4 units or pulmonary artery pressure exceeding 25 mmHg, either of which was considered as an absolute contraindication of the Fontan procedure. In the Fontan group, according to the ten requirements proposed by Choussat et al. [16] only one patient was considered as

TABLE 6. Previous operation

Procedure	Septation	Fontan
Blalock–Taussig shunt	2 (2 pts.)	52 (47 pts.)
Aorta–pulmonary shunt	0	7 (6 pts.)
Glenn procedure	0	3 (3 pts.)
Total cavopulmonary shunt	0	1 (1 pt.)
Pulmonary valvotomy	o	1 (1 pt.)
Pulmonary artery angioplasy	0	1 (1 pt.)
Pulmonary artery banding (PAB)	15 (15 pts.)	8 (8 pts.)
Blalock–Taussig shunt following PAB	2 (2 pts.)	2 (2 pts.)
Repair of coarctation of aorta	3 (3 pts.)	2 (2 pts.)
Norwood procedure	0	1 (1 pt.)
Atrioseptostomy	0	2 (2 pts.)
Total	22 (17 pts.)	78 (62 pts.)

Data are number of procedures with number of patients (pts.) in parentheses.

TABLE 7. Preoperative hemodynamic status

Measurement	Septation	Fontan
Arterial oxygen tension, mmHg	48 ± 8 (32–61)	40 ± 6 (27–53)*
Pulmonary/systemic flow ratio	1.8 ± 1.6 (0.6–3.0)	1.3 ± 0.7 (0.3–3.9)*
Mean pulmonary artery pressure, mmHg	29 ± 15 (9–60)	15 ± 4 (5–24)*
Pulmonary vascular resistance, U/m^2	3.2 ± 2.3 (1.0–11.0)	1.7 ± 0.8 (0.3–4.4)*
EDV of the main ventricle, % of normal	269 ± 95 (172–570)	203 ± 53 (92–366)*
Ejection fraction of the main ventricle, %	59 ± 7 (46–76)	54 ± (36–73)*

EDV, End-diastolic volume.
Data are mean ± standard deviation with range in parentheses.
*, $P < 0.05$.

TABLE 8. Status of the patients in the Fontan group according to Choussat's criteria

Number of criteria unfulfilled	*n*
0	1
2	16
3	22
4	21
5	17
6	7
7	4

an "ideal" candidate for the Fontan procedure. Most patients were outside the limits in more than three requirements, with a maximum of seven (Table 8).

Surgical Outcome

In the 21 patients in the ventricular septation group, there was no early death and only two late deaths, constituting 9.5%. All the long-term survivors are in good health. A complete AV block was present in 2 cases preoperatively and occurred in 3 additional cases postoperatively. The remaining 16 patients are in sinus rhythm. The actuarial survival estimate of the patients in the septation group was 89.5% at 8 years after operation (Fig. 1).

In the 92 patients in the Fontan group, there were 5 early deaths and 3 late deaths. The overall mortality was 8.7%. More than 90% of the long-term survivors are in New

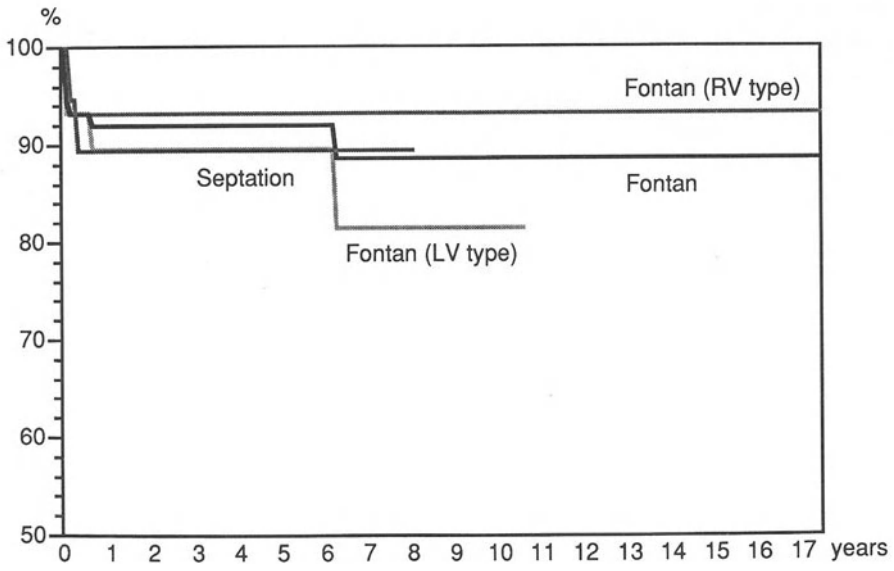

FIG. 1. Actuarial survival rate. *Septation*: Septation group ($n = 21$); *Fontan*: Fontan group ($n = 92$); *Fontan (RV type)*: the subgroup with right ventricular type morphology in the Fontan group; *Fontan (LV type)*: the subgroup with left ventricular type morphology in the Fontan group. No significant differences were detected by Cox–Mantel test

York Heart Association class I or II. The actuarial survival estimate of the patients with a univentricular heart of LV type in the Fontan group was 81.5% at 11 years after operation, and that of the patients with RV type was 93.3% at 17 years after operation, with 88.6% being the estimate for all patients in the Fontan group (Fig. 1).

Risk Factors for Death After Operation

Univariate analysis of various factors in the survivors and nonsurviv ors revealed higher LV peak pressure, higher LV end-diastolic pressure, greater LV wall thickness, and larger LV mass as risk factors for death after septation. Types of segmental anatomy, AV valve regurgitation, and surgical interventions to subaortic stenosis were not identified as significant risk factors (Table 9).

Univariate analysis revealed the number of requirements unfulfilled, pulmonary vascular resistance, pulmonary venous anomaly, preoperative low arterial oxygen tension, and longer aortic cross-clamp time as risk factors for death after the Fontan procedure (Table 10). Types of ventricular morphology, types of AV connection, heterotaxia, AV valve regurgitation, pulmonary artery branch stenosis, and previous pulmonary artery banding were not identified as significant risk factors.

Hemodynamic Changes and Postoperative Hemodynamic Status

End-Diastolic Volume

The preoperative end-diastolic volume of the main ventricular chamber was significantly larger in the septation group than in Fontan group (Table 11), which is consistent with the data in Qp/Qs. The smallest preoperative ventricular volume in the septation group was 172% of normal. After ventricular septation, the mean end-diastolic volume of the new pulmonic ventricle was 83% of normal (the minimum was 43%) and was approximately one-half that of the new systemic ventricle. In the

TABLE 9. Risk factors for death after ventricular septation procedure (univariate analysis)

Identified risk factor	*P* value
LV peak pressure (higher)	0.009
LVEDP (higher)	0.017
LV wall thickness (thicker)	0.023
LV mass (larger)	0.017

LVEDP, Left ventricular end-diastolic volume.

TABLE 10. Risk factors for death after Fontan-type procedure (univariate analysis)

Identified risk factor	*P* value
Number of requirements unfulfilled (larger)	0.006
Pulmonary vascular resistance (higher)	0.026
Pulmonary venous anomaly	0.008
PaO_2 (lower)	0.020
Aortic cross-clamp time (longer)	0.015

TABLE 11. Postoperative hemodynamic status

Measurement	Septation	Fontan
Right atrial pressure, mmHg	13.5 ± 3.3	13.9 ± 3.3
Cardiac index, l/min/mm^2	3.06 ± 1.17	2.75 ± 0.73
Systemic ventricular ejection fraction, %	55.7 ± 8.4	44.5 ± 10.0*
Systemic ventricular EDV, % of normal	159 ± 56	129.5 ± 49.5*
Pulmonic ventricular ejection fraction, %	64.0 ± 9.5	—
Pulmonic ventricular EDV, % of normal	83 ± 33	—

EDV, End-diastolic volume.
*, $P < 0.05$.

Fontan group, ventricular volume was reduced significantly after operation because of reduction in ventricular preload.

Ventricular Ejection Fraction

After septation, the ejection fraction of the new pulmonic ventricle was higher than that of the new systemic ventricle. Stroke volume of the smaller pulmonic ventricle was compensated by this high ejection fraction resulting from paradoxical motion of the artificial septum.

In the Fontan group, the ventricular ejection fraction significantly reduced after operation, partly from reduction in preload. The postoperative ejection fraction of the systemic ventricle was significantly higher in the septation group than in the Fontan group.

Postoperative Cardiac Index and Right Atrial pressure

The mean postoperative cardiac index was 3.1 in the septation group and 2.8 in the Fontan group. This difference did not achieve statistical significance. Mean right atrial pressure was 13.5 mmHg in the septation group and 13.9 mmHg in the Fontan group.

Discussion

Our experience with surgical treatment of the univentricular heart suggests that ventricular septation and Fontan procedures can be performed with excellent results in selected patients. The following points should be considered.

Indications

A patient with univentricular heart of the left ventricular type without tight pulmonary stenosis/atresia or AV valve atresia can be a candidate for ventricular septation. With the combined arterial switch procedure, ventricular septation is feasible in anatomy other than {S,L,L}. The ventricular septation procedure usually requires two AV valves of adequate size; however, it was feasible in a case with a common AV valve that was partitioned without prosthetic valve replacement.

AV valve regurgitation was quite common in both septation and Fontan groups. The presence of AV valve regurgitation in itself is not a contraindication to either the septation or Fontan procedure because it is usually correctable by valvuloplasty or annuloplasty. Surgical correction of AV valve regurgitation is very important for a

successful septation procedure, to abolish unnecessary ventricular volume load, and also for a successful Fontan procedure, to lower the pulmonary venous pressure. The minimum ventricular volume required for the septation procedure is probably about 150% of normal predicted volume. The smallest preoperative left ventricular end-diastolic volume in the present series was 172% of normal. Our present data indicate that a volume as small as 43% of normal for the new pulmonic ventricle can be tolerated because of relatively high ejection fraction of the pulmonic ventricle caused by paradoxical motion of the artificial septum [12].

Atrioventricular block had been a common complication of the ventricular septation procedure [1]. However, with improved understanding of the anatomy of the conduction system, surgical block can be avoided although AV block may occur as a consequence of their natural history in patients with AV discordance.

In patients with univentricular heart who fall outside the indications for the ventricular septation procedure, a Fontan-type procedure may be indicated. It is widely accepted that a low pulmonary vascular resistance is the key to a successful Fontan-type operation. The precise preoperative evaluation of the pulmonary vascular resistance is very important; however, often it is very difficult. Figure 2 shows the relationship between the preoperatively evaluated pulmonary vascular resistance and the pulmonary vascular resistance calculated by postoperative catheterization in the post-Fontan survivors. The plot indicates very poor correlation between the two measurements. If we assume that the postoperatively calculated resistance is the best representation of the true resistance because of more reliable measurement under unmixed circulation, it represents unreliability of the preoperative evaluation. Moreover, the postoperative value is often higher than the preoperative evaluation.

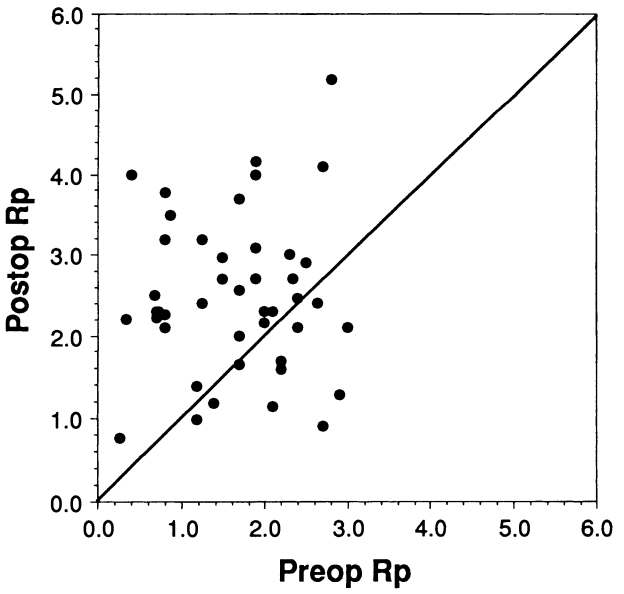

FIG. 2. Relationship between preoperative evaluation and postoperative measurement of pulmonary vascular resistance. *Preop Rp*: Pulmonary vascular resistance calculated from preoperative measurements in the catheterization laboratory; *Postop Rp*: pulmonary vascular resistance calculated from postoperative measurements in the catheterization laboratory

Several factors influence the preoperative evaluation of pulmonary vascular resistance by applying Fick's principle. In case of nonconfluent pulmonary arteries or severe branch pulmonary artery stenosis with different blood-flow source to the right and left pulmonary arteries, it is not possible to apply the principle to both lungs together. In such cases, pulmonary perfusion scintigraphy is useful to evaluate distribution of the pulmonary blood flow and to estimate the resistance in each lung. Measurement through a shunt or tight stenosis may underestimate the pulmonary artery pressure, and measurement of pulmonary venous wedge pressure may be more reliable.

In the presence of anomalous pulmonary venous return, it may be difficult to measure true pulmonary venous pressure in the same sense. Presence of systemic-to-pulmonary collaterals is another important factor. Preoperative coil-embolization of the collaterals helps accurate evaluation of pulmonary vascular resistance and a successful Fontan procedure. Intrapulmonary shunt may be present, especially in patients having had a previous Glenn procedure. This can be detected by contrast echocardiography or pulmonary scintigraphy. It is our routine to perform intraoperative direct measurement of pressures and blood flow to confirm the preoperative evaluations whenever possible.

Palliative Surgery and Timing for Definitive Repair

Patients with a univentricular heart usually require palliative surgery during the neonatal period or infancy, with the rare exception having naturally well-balanced systemic and pulmonary circulation [17]. Ventricular septation candidates usually need pulmonary artery banding, with or without repair of coarctation [18,19]. Early ventricular septation is recommended because reduction in ventricular volume and concentric hypertrophy by progression of subaortic stenosis may ensue [20].

Fontan candidates should undergo early and often repeated palliative procedures that prevent pulmonary hypertensive changes, i.e., tight pulmonary artery banding in patients without pulmonary stenosis, and which promote development of pulmonary vascular bed, i.e., adequate systemic-to-pulmonary shunt in patients with pulmonary stenosis or after initial pulmonary artery banding.

Patients with severe subaortic stenosis can be managed by either a Norwood procedure or Damus–Kaye–Stansel procedure when the ascending aorta is hypoplastic, or by subaortic resection when the ascending aorta is adequately large [21,22]. Enlargement of outlet foramen or subaortic resection should be performed at the time of definitive repair whenever morphological narrowing is noted, even with no demonstrable pressure gradient across the area, to prevent late development of significant stenosis [11].

Risk Factors for Death After Operation

In the septation patients, ventricular hypertrophy was a risk factor for death after operation. The ventricular hypertrophy may be associated with reduced myocardial contractility and compliance and with problems in myocardial protection during relatively long aortic cross-clamp time. Earlier operation before progression of myocardial hypertrophy should be encouraged.

In the Fontan patients most of the early deaths were associated with a high or unknown pulmonary vascular resistance, which highlights the importance of accurate

preoperative evaluation of pulmonary vascular resistance. The late deaths seemed associated with poor ventricular function, which may be related to preoperative myocardial dysfunction or decreased tolerance to ischemia.

Postoperative Status

Postoperative status of the long-term survivors seemed satisfactory in both groups. No statistically significant differences were demonstrated in postoperative cardiac index and right atrial pressure between the groups; however, it should be noted that pulmonary vascular resistance was significantly higher in the septation group than in the Fontan group.

Conclusions

Patients with univentricular heart can have definitive repair, either ventricular septation or Fontan procedures, with good results by careful preoperative management. Preoperative management includes systemic-to-pulmonary shunt operation for patients with decreased pulmonary blood flow and vascular bed, pulmonary artery banding with or without coarctation repair for patients with increased pulmonary blood flow, and sometimes multiple palliative surgery. Those patients should be reevaluated within a couple of years to assess the feasibility of septation or Fontan procedures.

Patients with univentricular heart of the left ventricular type with two adequate AV valves and without significant pulmonary stenosis can be good candidates for the septation procedure. Patients with a univentricular heart of either right or left ventricular type with an adequate pulmonary vascular bed and low resistance can be good candidates for the Fontan procedure. Close follow-up and early and repeated evaluations are most important for maximizing the chance of subsequent definitive repair in this patient group.

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The Future of Transcatheter Closure of Patent Ductus Arteriosus: Long-Term Study of 368 Procedures

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Summary. Gross and Hubbard performed the first successful surgical closure of patent ductus arteriosus (PDA) in 1938. In 1967, Porstmann pioneered nonsurgical catheter closure of the ductus. Rashkind developed a new collapsible umbrella for this purpose in 1979. Since then, the devices used experimentally in animals and, rarely, in humans for transcatheter closure of PDA have been an occluder–counter-occluder buttoned device, by Sideris; a double-balloon detachable silicone device, by Warnecke; a nylon sack filled with silicone coated guidewires, by Magal; occluding spring coils, by Gianturco; and a shape-memory polymer, polynorbornene, by Echigo. The most long-term experience worldwide has been with a double-disk Rashkind umbrella device. We attempted PDA closure in 368 infants, children, and young adults between December 1987 and November 1993. The male-to-female ratio was 1:2.4; patient age ranged from 11 months to 45 years (median age, 5 years) and 56 patients were less than 2 years old; patient weight was 7.4 to 69 kg (mean, 18.2 ± 9.5). Successful device implantation was achieved in 98% of cases (358/368); 10 technical failures occurred. Complications included 8 embolizations to a pulmonary artery, 3 self-limited episodes of hemolysis, and 2 episodes of induced supraventricular tachy-cardia. The device was retrieved by grabber in 4 patients and by surgery in 4 patients. Follow-up included echocardiography and Doppler studies with color flow mapping. At 6 months follow-up, 23% of the patients (72/319) had a small residual shunt. The incidence was 17% (46/276) in ductus with the narrowest diameter less than 6 mm and 60% (26/43) in ductus greater than 6 mm in diameter. Successful implantation of a second occluder device was achieved in 49 patients. A third device was implanted in 2 patients who had a residual shunt with a continuous murmur at 7 months follow-up. Overall, closure occured in 90% of patients seen 6 months after initial or repeated implantation. One patient developed bacterial endarteritis and septicemia 2.5 years after deployment of a second device and died of this complication. Follow-up ranged from 9 to 75 months with a mean of 48 months with no complications. This study confirms the efficacy of PDA closure with a Rashkind occluder, especially in patients with ductal diameter of less than 6 mm. Catheter closure with the Rashkind umbrella device is a viable alternative to surgical closure of PDA in selected infants, children, and young adults.

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Key words. PDA—Transcatheter occlusion—Umbrella closure—Cardiac catheterization

Introduction

Patent ductus arteriosus (PDA) is one of the commonest congenital cardiac anomalies compatible with survival through childhood to adult life. Beyond infancy, it was estimated by Campbell to carry a mortality of about 0.5% per year and to have a spontaneous closure rate of only about 0.6% per year [1]. The presence of such a duct has been accepted by most cardiologists as an indication for closure. It has been found, with many patients, that the presence of an unfragmented wavy subendothelial elastic lamina is associated with an increase in elastic tissue within the media. Intimal cushions, common in the functionally closed ductus, were sparse. Abnormal elastic tissue is a primary abnormality in PDA.

Gross and Hubbard performed the first surgical closure of PDA in 1938 [2]. Within a few decades, ductal surgery had become commonplace, safe, and effective. Porstmann et al. in 1967 pioneered nonsurgical closure of PDA using a preshaped Ivalon plug delivered via the femoral artery [3]. This was available only for larger children because of the relatively small size of the iliofemoral arteries in comparison to ductus size. Subsequently, in 1979 Rashkind and Cuaso developed a new device, a collapsible umbrella, which could be delivered via a venous or arterial approach. Bash and Mullins [5] modified the delivery system in 1985 using a transseptal long sheath transvenously through the ductus, making it easier to pass the stiff delivery system through the right heart. The umbrella has also been changed from a single to a double disk of polyurethane maintained on two collapsible spring-wired struts. Lock et al. [6] have further improved the technique to reduce residual leaks.

Two other transcatheter occlusion techniques have been applied in humans (Table 1): occluding spring coils for small PDAs (Gianturco et al. [7]) and an occluder–counter-occluder "button" device (Sideris et al. [8]). Three other experimental techniques have been described for PDA closure: Warnecke et al. [9] used a 5 F or 6 F triple lumen catheter with a detachable silicone double-balloon; Magal et al. [10] described a device made of a small nylon sack filled with segments of guidewire, fixed with a distal flexible crossbar, and delivered in a 10 F catheter system; and Echigo et al. [11] used a shape-memory polymer, "polynorbornene", delivered through the long sheath over a wire in the ductus region and splashed with warm water at 45°C to reexpand it in the PDA for complete closure. So far no clinical trials have taken place with these techniques. The greatest experience worldwide by far has been with Rashkind's double-disk device [12–17].

The results of a series of 368 nonsurgical ductal closure attempts in children and young adults using Rashkind's double-disk device between December 1987 and No-

TABLE 1. Transcatheter closure of patent ductus arteriosus (PDA)

Porstmann: Polyvinyl lvalon plug
Rashkind: double-disk polyurethane foam
Sideris: buttoned double-disk device
Warnecke: double-balloon detachable silicone
Magal: nylon sack filled with guidewires
Occluding spring coils
Echigo: shape memory polymer, polynorbornene

vember 1993 are presented. In this section we evaluate immediate and long-term effectiveness, safety, complications, effect of age, and the role of this device in the management of PDA in children and young adults.

Materials and Methods

A total of 368 procedures (109 on males, 259 on females) were performed on 317 patients ranging from 11 months to 45 years of age with a median age of 5 years. There were 56 patients less than 2 years of age and 312 patients more than 2 years of age; with their weight ranged between 7.4 and 69 kg; the mean weight was 18.2 ± 9.5 kg in patients aged 5 years and less and 24.8 ± 10.8 kg in those more than 5 years of age. A small number of patients had associated cardiac defects and a few had noncardiac defects (Table 2); 156 patients were symptomatic with a history of shortness of breath on exertion. The ECG results revealed left ventricular hypertrophy (LVH) in 154 patients, combined ventricular hypertrophy (CVH) in 28 patients, Wolff-Parkinson-White (WPW) syndrome in 2 patients, and congenital heart block in 2 patients; 4 patients had right ventricular hypertrophy (RVH). The remaining 180 patients showed a normal ECG. On chest X-ray, mild cardiac enlargement and a mild increase in pulmonary vascular markings were seen in 168 patients, moderate cardiac enlargement and increased pulmonary vascular markings in 44 patients, and normal chest X-rays in 156 patients.

Informed consent for transcatheter PDA closure was obtained. A right heart catheter study was completed from the right groin, including a descending aortogram through the ductus arteriosus, in the anteroposterior (AP) and lateral projection. The diagnosis of PDA was confirmed; the exact anatomy of the ductus and adjacent landmarks such as tracheal air shadow and vertebral relationships were identified during angiography. The narrowest diameter of the ductus was accurately measured; this should be less than 4 mm to obtain adequate fixation of a 12-mm occluder device.

TABLE 2. Catheter closure of PDA: associated defects

Defect	Number
ASD (small)	3
VSD (small)	5
Sub-AS (mild)	3
Pulmonary valve stenosis	3
Aortic valve stenosis	3
Mitral valve prolapse	5
Pulmonary hypertension	2
Arrhythmia (WPW 2, CHB 2)	4
Down syndrome (10) and rubella (3)	13
Cleft lip and palate	1
Hydronephrosis	1
Sprengel's deformity	1
Absent left kidney	2
Ehlers–Danlos syndrome	1
Rubinstein–Taybi syndrome	1
Right pulmonary vein aneurysm	1

ASD, Atrial septal defect; VSD, ventricular septal defect; Sub-AS, sub-aortic stenosis; WPW, Wolff-Parkinson-White; CHB, congenital heart block.

TABLE 3. Protocol for catheter closure of PDA

Excellent X-ray and fluoroscopy equipment
Clinical and echo evaluation
Angiography: PDA diameter
Device selection (12 or 17 mm)
Long sheath introduction (8 F or 11 F)
Loading of device and delivery into PDA
Repeat aortogram
Follow-up echo (12 h, 6 weeks, 6 months)

A 17-mm device is required for a ductus greater than 4 mm in diameter (Table 3). A second venous line was introduced from the left groin for supplemental medications, especially sedation, during critical phases of the procedure. An arterial monitoring line was also placed for systemic pressure measurements.

The methodology for the implantation of this occluder device followed closely that described by the Houston group using the Mullins 8 F long sheath for the 12-mm and an 11 F for the 17-mm occluder device, to deliver the device through the right heart into the PDA. The sheath was preformed in hot water to the shape of the right ventricular (RV) outflow tract, ductus, and descending aorta. A gentle curve was preformed on the distal end of the delivery wire and attaching mechanism to correspond approximately with the course of the ductus, and the extended wire loop on the ductus occluder was engaged over the knuckle on the distal end of the delivery wire. The occluder was then inserted into the loading device; from there it was transferred into the delivery pod of the delivery system. During the insertion of the occluder into the cone of the loader, great care is taken to ensure that the distal legs fold distally and the proximal legs fold proximally back toward the open end of the cone. The delivery pod at the distal end of the delivery catheter was advanced into the loader and with traction on the proximal end of the delivery wire the device was withdrawn into the pod and the system flushed to clear air bubbles.

At this time the patient was given a supplemental dose of ketamine intravenously. A cineangiogram was obtained through the long sheath across the ductus into the descending aorta in AP and lateral views. The delivery cathether was advanced through the long sheath to the inferior vena cava, right atrium (IVC–RA) junction. At this time, only the wire was advanced, with the occluder still folded, out of the pod to the distal end of the sheath. First the distal leg was released, then the entire system, including the sheath, was withdrawn until the distal legs flexed in the ductus. The proximal legs were then released by withdrawing only the sheath. Once the occluder was secured, the delivery sheath was advanced against the open proximal legs and the release mechanism activated, releasing the occluding device in the ductus (Figs. 1 and 2).

After the successful implantation of the occluder, either a retrograde arteriogram or a transseptal left heart catheterization was done by advancing the balloon catheter from the left ventricle to the ascending and descending aorta. One-quarter of our cases had transseptal left heart catheterization. The patient is also given a broad-spectrum antibiotic i.v., repeated every 6 h for three doses.

A chest X-ray in PA and lateral views and an echo Doppler study were done the following day. Patients were usually discharged on the day after the procedure with a clinic appointment and an echo Doppler study at 6 weeks, at 6 months, and at yearly intervals thereafter.

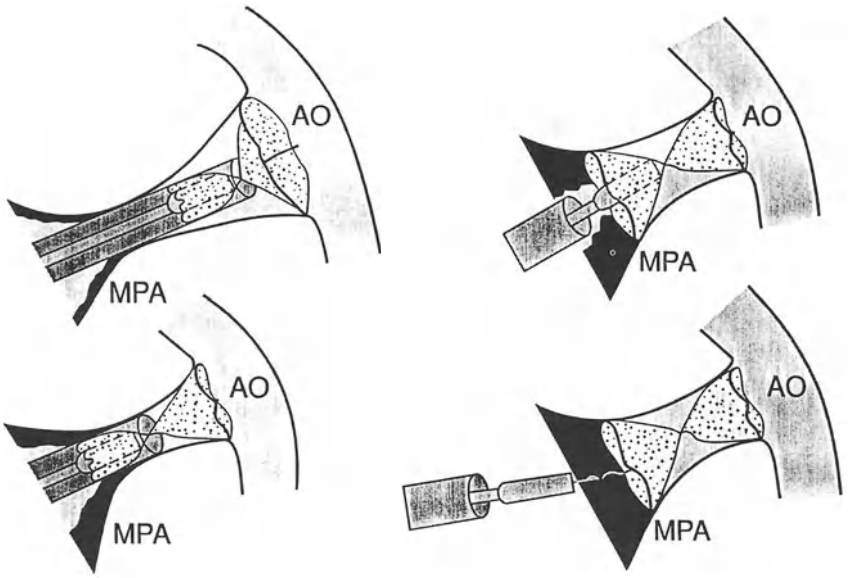

FIG. 1. Insertion of occluder device through sheath of delivery system. *MPA*, Main pulmonary artery; *AO*, aorta

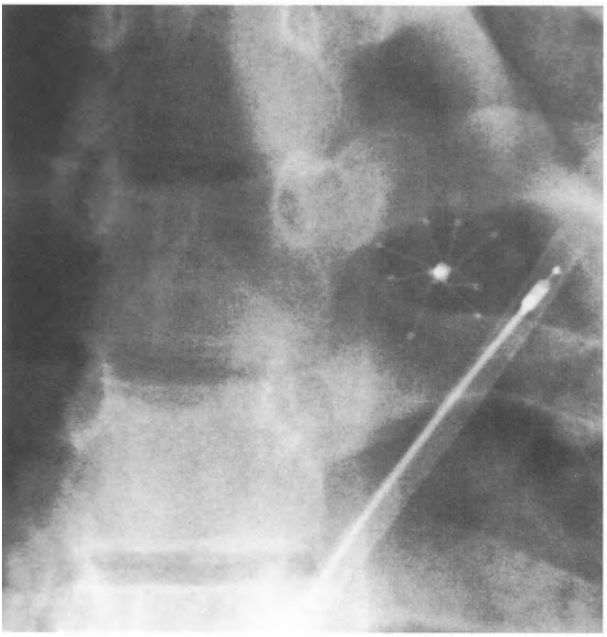

FIG. 2. Magnified antero-posterior (AP) angiocardiogram shows 17-mm Rashkind's umbrella in patent ductus arteriosus (PDA) and 11 F long sheath and delivery system in MPA

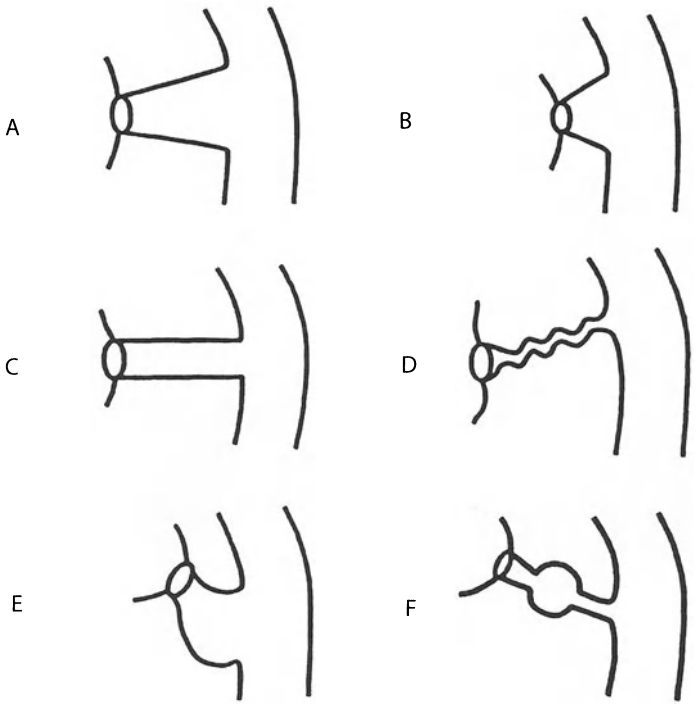

FIG. 3A–F. Catheter closure of PDA in six types of ductus in our series of 368 patients: long conical ductus (**A**), 47 patients (12.8%); short ductus (**B**), 229 (62.2%); long tubular ductus (**C**), 20 (5.4%); tortuous ductus (**D**), 1 (0.3%); pouchlike asymmetrical ductus (**E**), 69 (18.8%); and double-constriction ductus (**F**), 2 patients (0.5%)

The 12-mm device was used 197 times and the 17-mm device 171 times. The ductus diameter for the 12-mm device ranged from 0.5 to 4.5 mm (mean, 3.0 ± 0.73). For the 17-mm device, the duct diameter range was 3–12 mm (mean, 5.3 ± 1.3). There were 6 technical failures in use of the 12-mm device and 4 failures in use of the 17-mm device.

We categorized the ductus as one of six types in our series (Fig. 3): a long conical ductus (type A) was present in 47 patients (12.8%); a short ductus (type B) was seen in 229 patients (62.2%); a long tubular ductus (type C) was seen in 20 patients (5.4%); a tortuous ductus (type D) was seen only once as an isolated entity in our series; a pouchlike asymmetrical ductus (type E) was seen in 69 patients (18.8%); and a double-constricition ductus (type F) was seen twice (0.5%).

Results

Implantation was successful in 358 operations; implantation failed in 10 patients. A second device was implanted in 49 patients and a third device was implanted in 2 patients because of residual shunts present at 6 months after the implantation. Four patients required surgical closure of ductus and retrieval of the device after it embolized to the lung. They had an uneventful recovery (Fig. 4). The device embolized to

the lungs in eight patients, three to the right and five to the left lung. In four patients it was retrieved with a grabber uneventfully; four required surgery as mentioned. Two patients had WPW syndrome on ECG and supraventricular tachycardia (SVT) three times just before the procedure, requiring multiple DC shocks before the umbrella implantation procedure was continued (Table 4).

In three patients we were unable to release the device from the knuckle, requiring a second delivery system. In a 4-year-old patient requiring a 12-mm device, the pod became disconnected from the catheter in the long sheath. The second delivery system was also defective, as the distal wire at the sleeve became stretched easily causing nonrelease of the device in vitro. A third delivery system was used for this patient with uneventful recovery. All these device-related problems occurred in our early experience. Three patients with a large ductus who received a 17-mm device developed residual shunts and hemolysis for 2–3 weeks. Surgical intervention was not required, and the hemolysis ceased. One patient, a 5-year-old girl who was lost to follow-up, developed bacterial endocarditis and septicemia 2.5 years after deployment of the second 17-mm device and died of the complications (Table 4).

In the total series (which excludes the 10 technical failures), 238 patients (66%) showed patency at 15-min postimplantation angiography. In 143 of 358 patients

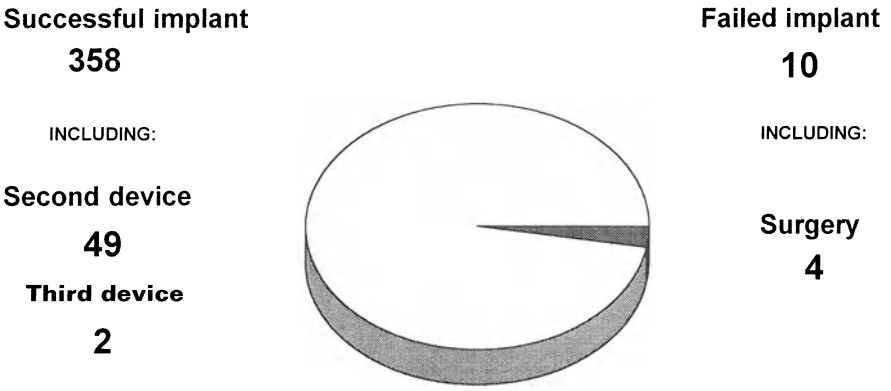

FIG. 4. Successful (358) and failed (10) (*shaded "slice"*) implants in catheter closure of PDA in our serics of 368 patients

TABLE 4. Complications of catheter closure of PDA

Patient	
Embolization	8
Retrieved	4
Surgery	4
Supraventricular tachycardia (WPW)	2
Device	
Unable to release	3
Pod disconnected	1
Wire stretched	1
Hemolysis	3
Endocarditis and septicemia	1

(40%), there was Doppler evidence of shunt patency 12 h post implantation. At 6 weeks, 88 of 333 patients (26%) showed patency, but at 6 months patency was present in only 72 of 319 patients (23%) examined (Fig. 5); it was unusual to see a residual shunt close after 6 months. Nine patients have been lost to follow-up.

Although it is more difficult to implant in the long ductus or in a pouchlike ductus, the ductus shape did not change the outcome of shunt patency. The type "C" long tubular ductus showed 22% residual shunts, the type "A" long conical ductus had 31% patency, and the type "E" pouchlike ductus had 25% patency (Table 5).

There were 310 patients with a PDA less than 6 mm in diameter. Implantation of the device failed in 7 of these patients. In the remaining patients, residual shunts were much less common; only 17% had residual shunts at 6 months follow-up (Fig. 6). Residual shunts were quite common when the narrowest ductal diameter was 6 mm or more. In this series, 58 patients had a ductus diameter of 6–12 mm (mean, 6.7 ± 1.1). In 3 of these patients, implantation was not successful. In the remaining 55 patients,

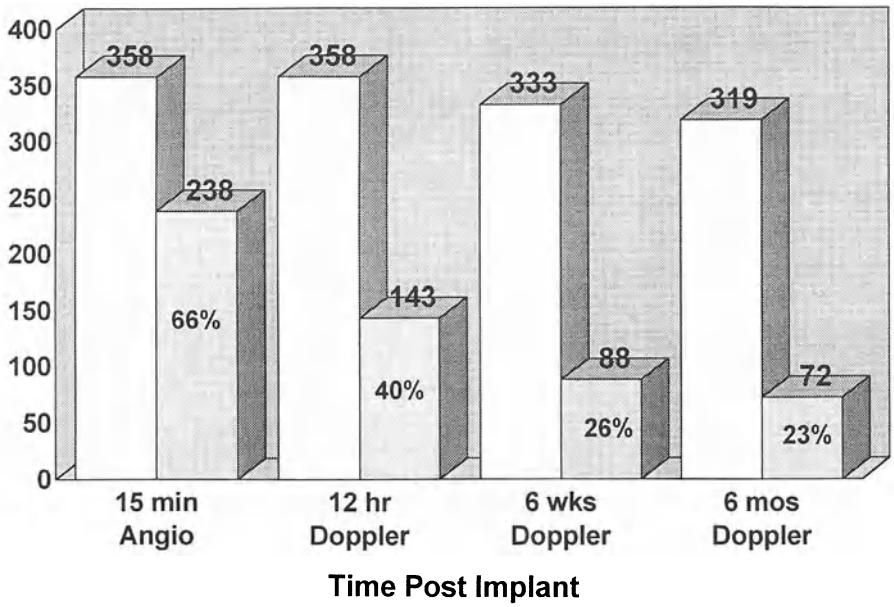

FIG. 5. Shunt patency at 15 min, 12 h, 6 weeks, and 6 months follow-up postimplantation in our series of 358 catheter closures of PDA (excluding 10 failures). *White bars*, Number of patients seen postimplantation; *shaded bars*, number of patients seen with patent shunts

TABLE 5. Rate of successful implantation for different shapes of PDA

Types of PDA	Number	Successful implantation	Success rate (%)
A (long conical)	47	46	98
B (short)	229	225	98
C (long tubular)	20	19	95
D (tortuos)	1	1	100
E (pouchlike asymmetrical)	69	65	94
F (double-constriction)	2	2	100
Total	368	358	98

There were 10 technical failures. Types are illustrated in Fig. 3.

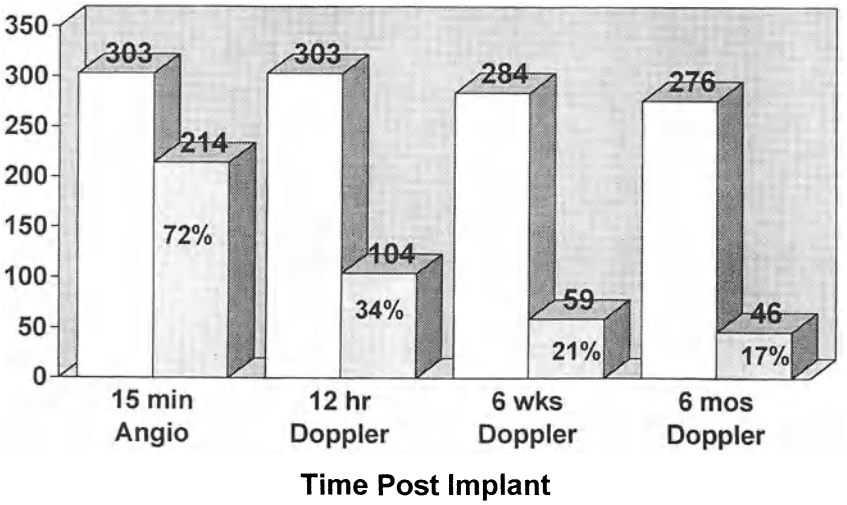

FIG. 6. Postimplantation shunt patency in catheter closures in 303 patients with PDA less than 6 mm (mean, 3.5 ± 0.99 mm) in diameter. Implantation failed in 7 of 310 cases. Residual shunts were much less common than in cases of larger diameter ducti. *White bars*, Number of patients seen postimplantation; *shaded bars*, number of patients with patent shunts

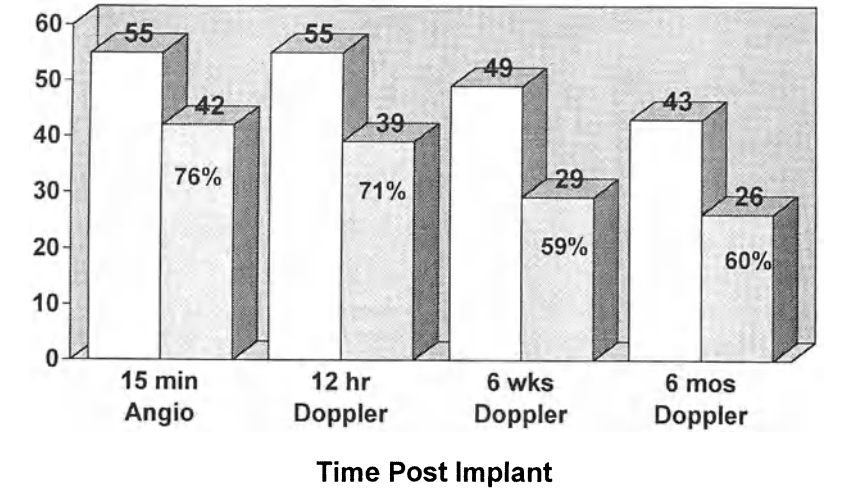

FIG. 7. Postimplantation shunt patency in catheter closures in 55 (3 of 58 attempts failed) patients with PDA 6–12 mm (mean, 6.7 ± 1.1 mm) in diameter. Note increased numbers (*shaded bars*) of residual shunts. *White bars*, Number of patients seen postimplantation

residual shunts were demonstrated at different intervals of follow-up by angiogram and Doppler studies. At 6 months follow-up, 60% showed residual shunts (Fig. 7). Ductal closure rate at 6 months follow-up with the use of the 12-mm device was better than when the 17-mm device was used, 83% versus 70% ($P = 0.006$) (Table 6).

The follow-up period ranged from 9 to 75 months with a mean of 48 months. At their latest follow-up study, patients were asymptomatic with no evidence of sequelae from the PDA non-surgical closure procedure.

TABLE 6. Comparison of 12-mm and 17-mm devices

Factor	12-mm device	17-mm device
Number of patients	197	171
Technical failures	6	4
Median age (years)	5 (11 months–21 years)	5 (1–45)
Weight (kg)	17.6 ± 8.0	19.0 ± 11.0
PDA diameter (mm)	3.0 ± 0.73 (0.5–4.5)	5.3 ± 1.3 (3–12)
12-h echo: % closed	69	47 ($P = 0.000$)
6-month echo: % closed	83	70 ($P = 0.006$)

Discussion

The advantages of transcatheter closure of PDA are that it obviates general anesthesia, thoracotomy, pain, and scar on the chest; it also obviates extended hospitalization, a prolonged convalescence period, pyschological trauma, and the need for blood products. In the presence of multiple associated cardiac defects, it simplifies the definitive surgical procedure. It is of course cost effective in Western countries.

The concerns in catheter closure of PDA are embolization to the pulmonary or systemic circulation. In our series there were no systemic embolizations, although there were 8 pulmonary embolizations. At 6 months follow-up, 23% of shunts were patent in 319 patients. Endocarditis has been seen once in our series, and it is a major concern for patients with residual shunts. Three patients with a residual shunt had continued hemolysis that did not require intervention. We have not seen left pulmonary artery stenosis in our series after deployment of the Rashkind's device. The limiting factors in the use of the occluder device are the size and weight of the patient. The absolute contraindications to the use of this device are the presence of PDA and pulmonary vascular disease or active endocarditis.

In conclusion, the catheter closure of PDA with the Rashkind's double-umbrella device can be achieved safely, as was seen in 98% of our patients. Initial complete closure of the ductus was noted in 77% of the patients in our series at 6 months follow-up. Safe reimplantation of a second device is possible for persistent shunts; 49 patients required a second umbrella closure and 2 patients a third umbrella device for complete closure (90%). In this series, on long-term follow-up there was 1 death and very low morbidity with this procedure. Greater success was experienced when the narrowest ductal diameter was less than 6 mm (87%).

Our results confirm that the use of this occluder device by pediatric cardiologists with experience in interventional cardiology presents a viable alternative to surgical closure of PDA in selected children and young adults.

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Intravascular Stents in Congenital Heart Lesions

Charles E. Mullins

Summary. Intravascular stent implantation, even with the current equipment and relatively crude delivery techniques, should be considered for the primary therapy of pulmonary branch stenosis and systemic venous stenosis.

Key words. Intravascular stents—Congenital heart disease—Pulmonary artery—Balloon angioplasty

Introduction

The dilation of branch pulmonary artery stenosis or systemic venous stenosis has been notoriously unsatisfactory as a long-term therapy. Although the acute dilation may initially open the stenotic lesion, there is usually either immediate recoil of the vessel or, alternatively, restenosis over the course of days to weeks. There often may be a "statistically significant" increase in the narrowest diameter, but virtually never an expansion to a permanent normal vessel diameter by balloon dilation alone. The use of the Palmaz [Johnson and Johnson (J&J), Warren, NJ, USA] balloon expandable intravascular "iliac" or, occasionally, "renal" stents to support these dilated areas has resulted in a remarkable long-term as well as immediate improvement in the area of stenosis, along with dramatic pressure improvement across the previously stenotic areas.

Intravascular Stent Implantation

The technique for implant of intravascular stents requires good biplanar angiographic equipment with angulation capabilities. The area(s) of stenosis are visualized in the views that most elongate the stenosis or that best separate several areas of stenosis. Once the area of stenosis is clearly identified, the end-hole catheter is advanced to a position as far distal as possible to the area of stenosis and still in as large a vessel as is possible. A second venous (angiographic) catheter is introduced and positioned just proximal to the area of stenosis and still in as large a vessel as is possible. A second venous (angiographic) catheter is introduced and positioned just proximal to the area

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of stenosis. A very stiff exchange-length 0.038-inch guidewire is delivered through the end-hole catheter to a location as far distal to the stenosis as possible. The catheter is removed, leaving the wire in place well across the stenosis. The branch stenoses usually are not predilated. A large (11 or 12 F) long sheath/dilator set is maneuvered over the stiff exchange wire past the area of stenosis; the dilator is then removed, leaving the stiff wire and sheath in place. An angiocardiogram through the second catheter is performed to visualize any distortion or changes in anatomy caused by the large sheath and stiff wire.

The J&J Stent

The J&J stent is mounted on a balloon that is the exact length of the stent and has the same diameter as the nearest normal vessel adjacent to the stenotic area. The catheter with the balloon-mounted stent is delivered to the area of stenosis over the wire and through the sheath. Once it is exactly centered in the area of stenosis, while the balloon catheter/stent and wire are held in a fixed position, the sheath is withdrawn off the balloon/stent. A repeat angiocardiogram is obtained to verify the exact position of the stent within the stenosis. Once the stent is in the exact desired location, the balloon with the stent is expanded to the maximum recommended pressure of the particular balloon or until the area of stenosis disappears with the stent expansion. The balloon is deflated rapidly. After several inflations to ensure maximum stent expansion and fixation within the vessel, the balloon is deflated with continual mild negative pressure and is removed, leaving the stent in place, holding the vessel open. If there is still a significant "waist" in the expanded stent after implant with a standard pressure delivery balloon, it can be further expanded with a "high-pressure" balloon passed over the same wire.

Because the maximum diameter achievable for a particular vessel is determined by the maximum expansion of the particular stent, the J&J "iliac" stent, expandable to 18 mm, was utilized for all proximal pulmonary branches and for all central systemic veins. Even if this stent was not expanded to its full diameter at the time of implant, it still has that potential by a reexpansion at a later date. Besides single pulmonary artery stents, there are tandem stents, bifurcation stents, and systemic venous stents that require simultaneous implants.

Discussion

In 5 years of clinical trials, 214 stents have been implanted in 128 patients with many tandem or bilateral stents. The majority of the patients in the study were more than 6 years of age and many had had some type of operative repair involving the pulmonary arteries. They often had several reoperations on their pulmonary arteries and still were considered inoperable or untreatable at the time of stent implant. With the stent implant, there was almost universal and dramatic improvement in the vessel diameter, which often increased up to normal size with an associated total relief of gradients in the areas of previous stenosis. A significant improvement in symptoms usually accompanied the hemodynamic improvement.

The smaller "renal" stents have been utilized in the smaller distal branch pulmonary arteries or in branch systemic veins. However, these smaller stents have been avoided in the proximal or central vessels except as a lifesaving procedure to buy time before further surgery. Although they can be delivered through a 7 or 8 F system, the

"renal" stents can only be expanded to a final maximum diameter of 10 mm. With normal growth, this diameter would represent a stenosis in a larger patient unless the stent was surgically removed or incised to expand the area during subsequent surgery. The use of the "iliac" stents in smaller patients has been limited to very ill patients weighing less than 10–12 kg. The larger stents, however, if at less than full expansion when initially implanted, can be further dilated up to the maximum diameter of the stent up to as long as 3 years later.

Approximately three-fourths of the stents implanted have been restudied both hemodynamically and angiographically after at least 1 year. In these patients, there has been an 1.5% incidence of significant restenosis. In spite of the initial complexity and severity of the lesions in the overall series of this patient group, there has been a minimal number of significant complications.

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Cardiovascular Problems in Kawasaki Disease

Hirohisa Kato

Summary. Kawasaki disease (KD) is an acute febrile illness recognized most often in children younger than 4 years of age. This is an acute systemic vasculitis syndrome of unknown etiology that has been recognized not only in Japan but also all over the world. KD is now a leading cause of acquired heart disease in children in North America and Japan. The most important clinical problems are the cardiovascular sequelae, particulary coronary artery, which may cause sudden death or severe dysfunction of the heart. From 1973 to 1993, we experienced 1545 acute KD patients and followed them by echocardiography and coronary angiography. From this study, we analyzed the clinical spectrum of cardiovascular involvement, myocardial infarction in KD, natural history of coronary aneurysms, the long-term pathology of the coronary artery, and issues in adult cardiology.

Key words. Kawasaki disease—Coronary aneurysms—Coronary angiography—Atherosclerosis—Myocardial infarction

Introduction

Kawasaki disease (KD), or mucocutaneous lymph node syndrome, is an acute febrile illness recognized most often in children younger than 4 years of age [1]. It is characterized by mucosal inflammation, indurative edema of the hands and feet, skin rash, and cervical lymphadenopathy. This is an acute systemic vasculitis syndrome of unknown etiology that has been recognized not only in Japan but also all over the world. The most important clinical problem is cardiovascular involvement, which may produce sudden death or may develop into coronary artery disease [2]. In 1973, we attempted to perform coronary angiography in an infant of 4 months of age just after the acute stage of KD and found multiple aneurysms in both right and left coronary arteries [3].

From 1973 to 1993, we experienced 1545 cases with acute KD. Until 1978, coronary artery lesions were evaluated in all cases by coronary angiography (CAG) because it was the only way to evaluate coronary aneurysm at that time. From 1979 to 1982, both two-dimensional echocardiography (2DE) and CAG were performed just after the acute stage of the illness. Since 1983, patients were selected for CAG by 2DE. From our

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experience, we summarize here the cardiovascular problems and management of patients with KD.

Cardiovascular Spectrum of Acute or Subacute Kawasaki Disease

The evaluation of the coronary artery in KD is a very important issue, and at the present time this is performed by CAG or 2DE. Since 1983, 2DE has become the most useful noninvasive method to evaluate coronary aneurysms. By using 2DE we have correctly diagnosed aneurysms of the left main coronary artery with 98% sensitivity and 95% specificity. The evaluation for right coronary artery was less sensitive. From echocardiographic studies, it became evident that coronary dilatation appeared on approximately the tenth day of illness, and more than half of the patients had mild coronary dilatation in this period. However, most of these were transient dilatations and regressed within 3–5 weeks of illness. Coronary aneurysms have developed in about 19% of these patients. A giant coronary aneurysm (of diameter more than 8 mm) was seen in about 5% (Table 1).

The coronary artery lesion is the most important lesion in KD. However, aneurysms in other arteries such as the axillary, iliac, or renal arteries were observed in 27 patients (1.7%). We were able to palpate the axillary aneurysms by daily physical examination. Such patients almost always have coronary aneurysms as well. If the patient has a renal artery lesion, renovascular hypertension may develop. There are several reports on digital gangrenous changes; however, we had no such experience. The prognosis of systemic artery aneurysms is generally favorable.

We demonstrated acute mitral regurgitation in 12 cases (0.7%). In most of the patients this eventually disappeared after a few months to several years [4]. The etiology of this condition may be considered to be valvulitis or papillary muscle dysfunction caused by myocarditis or ischemia. We had 3 patients with aortic regurgitation. Pericarditis or pericardial effusion appeared in 18% of the patients who were in the acute phase; this was mostly subclinical and disappeared within 1–2 weeks. Massive pericardial effusion or cardiac tamponade was rare. There have been no reports on the progression to chronic or constrictive pericarditis.

TABLE 1. Cardiovascular spectrum in Kawasaki disease

Condition	
Coronary artery	
Transient dilatation in acute stage	247/923 (26.7%)
Coronary aneurysm	263/1545 (17.0%)
1991–1993: gammaglobulin treatment selected by Harada's score	14/190 (7.3%)
Systemic artery aneurysms:	
Axillary, iliac, renal etc.	27/1545 (1.7%)
Mitral regurgitation	12/1545 (0.7%)
Aortic regurgitation	3/1545 (0.2%)
Pericarditis or pericardial effusion	212/1236 (17.1%)
Myocarditis	Probably more than half
Myocardial infarction	21/1545 (1.3%)
Fatal cases	8/1545 (0.5%)

Kurume University, 1973–1993.

Relatively mild myocarditis was observed in many patients who were in the acute phase, especially in the first and second weeks of illness, regardless of the presence of coronary aneurysms. Gallop rhythm, distant heart sound, ST-T segment changes, and decreased voltage of R waves on EKG may suggest the presence of myocarditis. In many instances, cardiac enzyme levels, such as creatine phosphokinase, did not change significantly. Cardiomegaly or decreased ejection fraction of the left ventricle caused by myocarditis was noted in some patients. This generally followed an acute course to resolution, seldom developing into a chronic condition or to cardiomyopathy. Myocardial infarction occurred in 21 patients (1.3%), 8 of whom died.

Analysis of Myocardial Infarction and Fatal Cases

The main cause of death was acute myocardial infarction (Fig. 1). We analyzed 195 cases with myocardial infarction (MI) from the nationwide survey in Japan [5]. MI mostly occurred within 1 year of illness; however, late deaths several years after acute KD have increased recently. The main symptoms of acute MI were shock, unrest, vomiting, and abdominal pain. Chest pain was more frequently recognized in the survivors and in children older than 4 years. Asymptomatic MI was seen in 37%; 22% had died at the first attack, and 16% of the survivors from the first attack had a second attack.

From the coronary angiographic studies in patients with MI, most of the patients who died had obstructions in the left main coronary artery or in both the right main coronary artery and the anterior descending artery. In survivors, one-vessel obstruction, particularly in the right coronary artery, was frequently recognized. Of the patients who survived acute MI, about half had various types of complications, such as ventricular dysfunction, mitral regurgitation, or arrhythmias, and these occurred even in those who had asymptomatic MI.

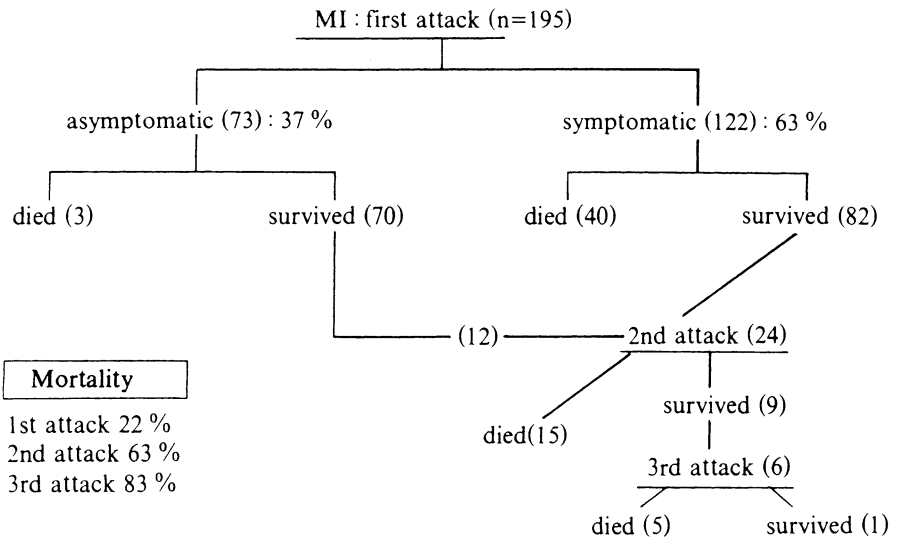

FIG. 1. Prognosis and mortality in patients with myocardial infarction

Natural History of Coronary Artery Lesions and Follow-Up

The natural history of KD or the fate of coronary aneurysms is the important issue of this disease [6]. Follow-up coronary angiography (Fig. 2) was performed in 205 patients who previously had coronary aneurysms 1–2 years after the first study. All patients have been followed for more than 2 years, with the longest follow-up being 20 years. Fifty-four percent of the patients demonstrated completely normal angiographic findings at the second study, which suggested that coronary aneurysm in KD shows a strong tendency of regression.

None of the patients with regression of coronary aneurysms had cardiac symptoms in the long-term follow-up periods, and results of their EKG, exercise stress test, thallium myocardial scintigraphy, and left ventricular function were all within normal limits. In contrast, the second coronary angiography of the other 94 patients showed abnormal findings, such as obstructive lesions or persistent aneurysms of the coronary artery. Some of these patients had various cardiac symptoms such as sudden death or MI and cardiac dysfunction. From this study, it is estimated that about 30% of patients with KD may develop ischemic heart disease.

When does this condition occur? We studied the time and the incidence or regression or progression to obstructive lesions from the onset of KD using the Kaplan–

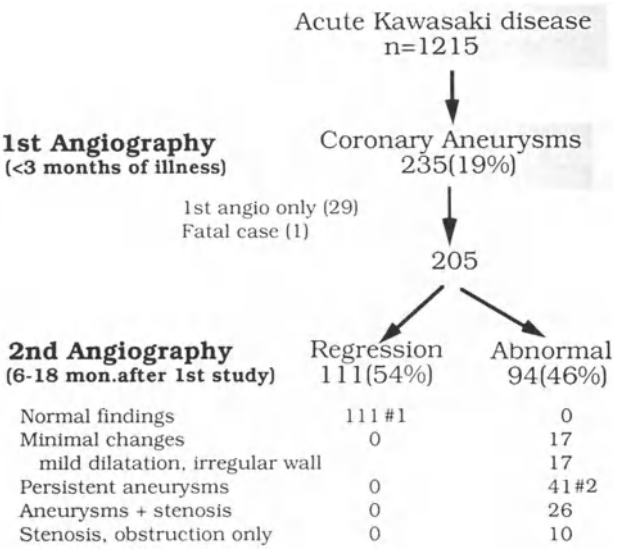

FIG. 2. Fate of coronary aneurysms: follow-up coronary angiography

Meyer life table method. Regression of coronary aneurysms mostly occurred within 2 years from the onset of illness; the obstructive lesions developed in 2 years and gradually increased in several years.

We investigated various factors that could affect the prognosis of coronary aneurysms [7]. The most important factor to predict prognosis was the size of coronary aneurysms. By discrimination analysis, we found the risk factors for coronary aneurysms to develop into ischemic heart disease to be aneurysms of diameter more than 8 mm, aneurysms having a large diffuse or saccular shape, prolonged fever for more than 21 days, treatment with steroids rather than aspirin, and age at onset more than 2 years. Thus, the giant coronary aneurysm is a serious problem because it is likely to produce massive thrombus formation and develop into ischemic heart disease. The incidence of giant coronary aneurysms is 26% in the patients with coronary aneurysms and is 5.5% among all patients with KD in our series.

The Pathological mechanism of aneurysm regression is marked proliferation of the intima without massive thrombus formation, which consists of rich, smooth muscle cells and well-regenerated endothelium covering a superficial thrombus [8]. Hemodynamic forces may regulate such arteries to maintain adequate lumina. It is uncertain whether intimal thickening eventually leads to the obstructive lesions. However, from our long-term follow-up study of the patients who had regressed aneurysms, so far it seems such an aneurysm does not progress to occlusion if massive thrombus formation is absent.

Vasculitis in Kawasaki Disease May Be an Atherosclerotic Risk Factor

Pathology of the coronary artery in KD several years after onset demonstrates the marked intimal proliferation, and in some patients, calcification deposits of protein-like material and hyalinized degeneration in the thickened intima, which are quite similar to arteriosclerotic lesions [9]. The important issue is whether these coronary artery lesions may develop to atherosclerotic coronary artery disease in adulthood. So far, however, the atheromatous lesion has not been recognized in the pathological specimens in KD.

We studied distensibility of the coronary arterial wall by intracoronary infusion of isosorbide dinitrate [10] (Fig. 3). In patients with persistent aneurysms or stenotic lesions, the portion with such lesions demonstrated significantly poorer distensibility. In patients with regressed aneurysms at an early stage, such as 1–2 years from the onset, there is no significant difference compared with the normal group; however, the group at a later stage, such as 8 years from the onset, showed lower distensibility.

These results suggest that the coronary artery may become stiff even in regressed aneurysms. Our recent intravascular ultrasound study of the coronary artery after KD demonstrated marked thickening of the intima and calcification in coronary aneurysms, which are similar to those of arteriosclerotic lesions [11]. The lipids profiles in KD indicate that high-density lipoprotein (HDL) cholesterol is lower and lipoprotein lipase activity is persistently depressed in the acute and subacute stages. It is reported that abnormal lipid profiles persisted for the long term [12]; however, our long-term study demonstrated that those abnormalities in the lipid profile became normal in several years in the long-term follow-up [13].

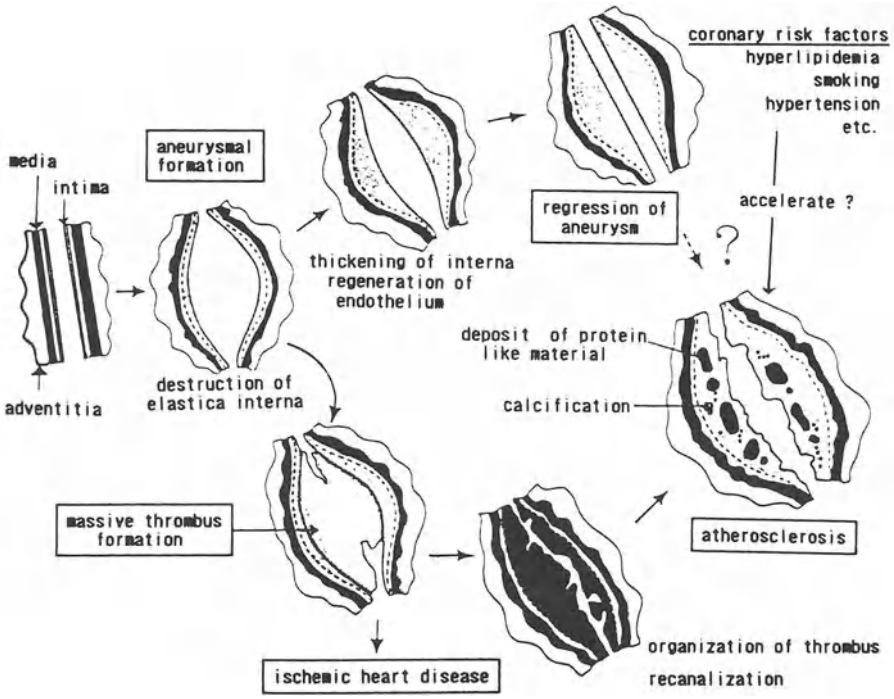

FIG. 3. Pathological sequence of Kawasaki vasculitis

Cardiovascular Sequelae of Kawasaki Disease in Adult Cardiology

It has now been more than 20 years since the first description of KD as a new clinical entity, and some of the early KD children are now in adulthood. We surveyed these adults to investigate any coronary sequelae that may likely result from their earlier KD and to report their cardiac conditions [14]. Questionnaires were sent to adult cardiologists in 354 major hospitals throughout Japan, with a response rate of 45.8%. Twenty-one adult patients with coronary lesions having a definite or suspected history of KD, including 17 men and 4 women whose ages ranged from 20 to 63 years (mean, 34 years), and 109 other cases with coronary aneurysms that had no documented history of KD were reported. Most patients (19/21) were not diagnosed as KD because they suffered from suspected Kawasaki disease before Dr. Kawasaki's first description.

The clinical presentations were acute myocardial infarction in 5 patients, old myocardial infarction in 6, angina pectoris in 9, and dilated cardiomyopathy in 1. Sixteen of 19 patients had more than two vessel obstructions. Three patients had already died suddenly, and 18 were alive, although with serious sequelae such as mitral regurgitation, arrhythmias, and congestive heart failure. These 18 were receiving medication; bypass surgery had been performed for 9 of them, and mitral valve replacement was done for 2.

The coronary artery sequelae of KD (Fig. 4) may be an important cause of ischemic heart disease in young adults, and adult cardiologists should be aware of this condi-

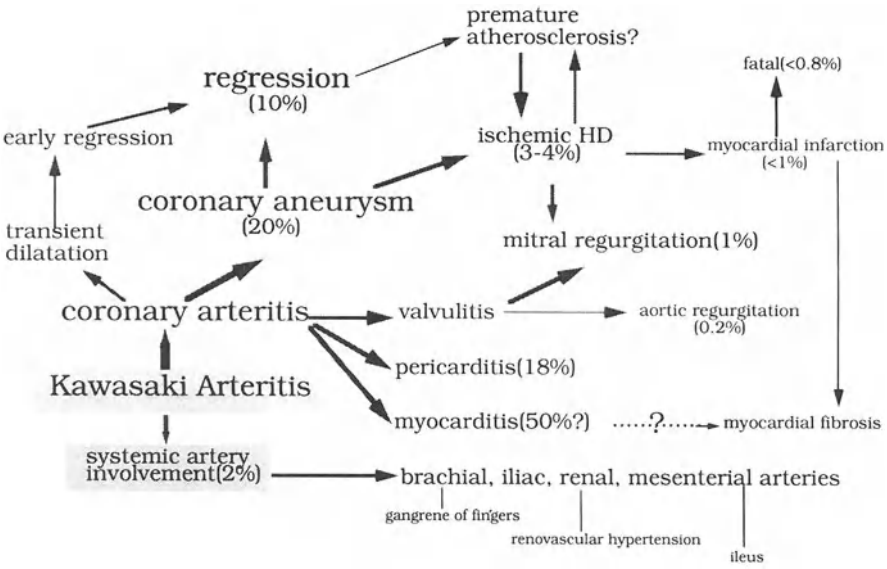

FIG. 4. Natural history of Kawasaki disease (cardiovascular sequelae)

tion and determine any history of childhood KD when they examine a patient with ischemic heart disease, particularly a patient under 40 years of age [15].

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Surgical Treatment of Coronary Artery Lesions in Kawasaki Disease

Mitsuru Aoki and Yasuharu Imai

Summary. The surgical treatment of coronary artery lesions in Kawasaki disease is reviewed. Surgical treatment of coronary obstructive lesions in Kawasaki disease has been performed using autologous saphenous vein grafts and arterial grafts, mainly from internal thoracic artery, when there is substantial myocardium in ischemia or at risk of infarction and the distal coronary artery is graftable. A recent multi-institutional study conducted in Japan has shown that the mortality and morbidity of coronary artery bypass surgery for coronary lesions in Kawasaki disease are acceptably low, and the long-term results have improved with use of arterial grafts, especially for young patients. However, the precise role of coronary bypass surgery in the treatment of coronary artery lesions in Kawasaki disease is still to be determined by comparisons of natural prognosis, long-term results of medical management including percutaneous transluminal coronary angioplasty, and the long-term results of evolving surgery.

Key words. Kawasaki disease—Coronary artery disease—Myocardial revascularization—Coronary artery bypass grafting—Internal thoracic artery

Background

Coronary artery lesions resulting from coronary arteritis in patients with Kawasaki disease [1] may cause sudden death or severe cardiac insufficiency [2]. The coronary artery lesions in Kawasaki disease include coronary aneurysms, thrombosis in the aneurysm, coronary artery stenosis caused by intimal thickening, total occlusion of the coronary artery with collateral circulation, and myocardial infarction [3]. It has been reported by Kato and colleagues [4] that approximately 20% of the patients with Kawasaki disease develop coronary aneurysms, that approximately 40% of those patients continue to have the aneurysms, and that in a substantial number of patients the lesions would progress to obstructions of the coronary arteries. Because of the substantial risk of sudden death and cardiac insufficiency, surgical treatment had been considered.

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Indications for Surgical Treatment

Surgical treatment of coronary obstructive lesions in Kawasaki disease may be indicated when there is substantial myocardium in ischemia or at risk of infarction and the distal coronary artery is graftable. The presence of ischemia and the viability of the myocardium should be evaluated in comprehensive reference to the presence of symptoms, electrocardiography, thallium scintigraphy, echocardiography, and left ventricular regional wall motion [5]. However, the precise indications of surgical treatment have not been established, because the natural prognosis, the early and long-term results of rapidly advancing medical management, and the early and long-term results of surgical treatment have been largely unknown.

History and Current Results of Surgical Treatment

Coronary artery bypass grafting in a child with Kawasaki disease was first reported by Kitamura and colleagues [6], utilizing an autologous saphenous vein graft, in 1974, followed by a successful use of the subclavian artery as a graft by Mains and colleagues [7] in 1981, the internal thoracic artery (ITA) by Kitamura and associates [8] in 1985, and the gastroepiploic artery (GEA) by Takeuchi and associates [9] in 1990, seeking for a graft with better long-term patency.

A multi-institutional cooperative study of 168 patients with Kawasaki disease in Japan [10] has shown that the long-term patency rate is significantly higher for arterial grafts (ITA and GEA) (77.1% $\pm$ 1.1%) than for vein grafts (46.2% $\pm$ 6.3%) 85 months after the operation ($P < 0.003$). It also has demonstrated significantly higher survival in patients with arterial grafts than in patients with vein grafts alone (98.7% $\pm$ 1.2% versus 81.6% $\pm$ 7.0%, $P < 0.05$) at 90 months after the operation with late death strongly related to the absence of an ITA graft ($P < 0.003$). These data suggest that ITA for the left coronary arteries and GEA for the distal right coronary arteries are the grafts of choice in this patient group.

The patency of saphenous vein grafts was particularly poor in small children. In patients less than 7 years of age, the patency rate of 27.7% for the saphenous vein graft was particularly poor when compared with 70.3% for the arterial graft. In contrast, saphenous vein graft patency was much better in patients more than 8 years of age, being 65.4%, and was not significantly different from the patency rate for the arterial graft [10]. One of the reasons for the better patency of the arterial graft in the young age group is thought to be its potential to enlarge both longitudinally and circumferentially in accordance with the growth of the patient. Kitamura and colleagues [11] have shown by serial angiographic measurements of length and diameter of internal thoracic arterial grafts that these grew significantly during a period exceeding 1 year, while the saphenous vein grafts did not show significant changes in length and diameter over a comparable period of time. It has been shown that the internal thoracic arterial graft increases its length relative to the increase in body surface area, but also has a potential to increase its diameter relative to the demand as native coronary stenoses progress.

Although incomplete revascularization is common, long-term clinical status after coronary artery bypass grafting in patients with Kawasaki disease appears satisfactory, as the multi-institutional study reported that 84% of the patients were in good health and 71% were free from postoperative cardiac events [10].

Conclusions

Mortality and morbidity of coronary artery bypass surgery for coronary lesions in Kawasaki disease seem acceptably low, and the long-term results have improved with the use of arterial grafts, especially for young patients. However, the precise role of coronary bypass surgery in the treatment of coronary artery lesions in Kawasaki disease is still to be determined by comparisons of natural prognosis, long-term results of medical management including percutaneous transluminal coronary angioplasty, and the long-term results of surgery.

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Ventricular Arrhythmias After Corrective Surgery of Tetralogy of Fallot

Regente I. Lapak[1], Eden D. Latosa[1], and Luis M. Mabilangan[2]

Summary. Ambulatory 24-h electrocardiographic monitoring with a Holter recording system was performed in 26 patients after repair of tetralogy of Fallot. The occurrence and severity of ventricular arrhythmia (VA) were studied relative to operative age, follow-up period after corrective surgery, type of surgical approach, postoperative right ventricular (RV) pressure, residual ventricular septal defect, and RV outflow tract pressure gradient. Significant VA (Lown grade 2–5) were detected in 7 patients (27%). Patients with significant VA (group I) were older (9.14 ± 2.9 years) at operation than those without VA (group II) (5.84 ± 2.2 years). Age at ambulatory monitoring was higher in group I (13.71 ± 1.89 years) than in group II (10.35 ± 3.91 years). Thus, it was observed that serious VA was related to higher age at the time of operation and at the time of ambulatory monitoring.

Key words. Ventricular arrhythmia—Tetralogy of Fallot

Introduction

Operative mortality of tetralogy of Fallot (TOF) has decreased tremendously during the past two decades. Following successful repair, almost all children catch up in terms of weight and height and may even grow faster than their peers. However, some investigators have recognized that late sudden death can occur as a rare postoperative complication of TOF repair, although previous studies have indicated that late cardiac arrest was caused by the progression of a bifascicular block to complete heart block. Studies have shown patients with manifest ventricular arrhythmias (VA) to be at higher risk for sudden death [1–8].

The objective of this chapter is to identify risk factors in the subsequent occurrence of ventricular arrhythmias among pediatric patients diagnosed as having TOF who had corrective surgery at the Philippine Heart Center.

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Materials and Methods

Rhythm evaluation was performed in 26 nonrandomized pediatric patients who underwent corrective surgery for TOF with ages ranging from 0.5 to 13 years. Patient age at the time of 24-h ambulatory electrocardiography with Holter monitoring ranged from 1.6 to 18 years. Excluded from this study were patients who had arrhythmias before surgery. VAs recorded from the Holter monitor were graded using the modified Lown's criteria [9] as described by Deanfield et al. [10], which are as follows: grade 0, no ventricular premature contractions (VPCs); grade 1, uniform VPCs with peak hourly count less than 30; grade 2, more than 30 VPCs; grade 3, couplets or multiform VPCs with peak hourly count less than 30; grade 4, couplets or multiform VPCs greater than 30; and grade 5, ventricular tachycardia, defined as equal to or more than 3 consecutive PVCs with a rate greater than 10 per minute.

Ventricular arrhythmia is considered significant when it is grade 2 or higher. Based on the severity of the grading, the patients were divided into two groups: group I, those who have grade 2–5 of modified Lown's criteria, and group II, those with grades 0–1. Clinical data of the two groups of patients were compared with regard to the following: (1) age at corrective surgery; (2) age when the 24-h Holter monitoring was done; (3) interval between surgery and Holter monitoring; (4) operative procedure; (5) duration of cardiopulmonary bypass; (6) right ventricular (RV) pressure after cardiopulmonary bypass and (7) pressure gradient across the right ventricular outflow tract (RVOT) using Doppler echocardiography. Fisher's exact test and the compared Student's *t*-test were used for statistical analysis.

Results

Incidence and Severity of Ventricular Arrhythmia

All patients had complete right bundle branch block on standard electrocardiogram, and VA was detected in nine patients. The frequency of VPCs in a 24-h period is shown for all patients in Table 1: over 1000 VPCs occurred in 24 h in one patient, 100–999 in five, 10–99 in one, and 1–9 in two patients. The severity of VAs is seen in Table 2; grade 1 in two patients, grade 2 in six, and grade 5 in one patient.

Comparison of Clinical Data

Age at corrective surgery (Table 3) was higher in group I (9.14 ± 2.91 years) than in group II (5.84 ± 1.89 years). Figure 1 shows the relation between age at surgery and

TABLE 1. Total number of ventricular premature contractions (VPCs) in 24 h

Total VPCs	No. of patients
0	17
1–9	2
10–99	1
100–999	5
>1000	1

TABLE 2. Severity of ventricular arrhythmia (VA)

Lown grade	No. of patients
0	17
1	2
2	6
3	0
4	0
5	1

the grade of VA. A patient who was operated on at age 13 years had runs of VPCs (Lown grade 5). The incidence of VA increased with age at surgery. Likewise, age at ambulatory monitoring was higher in group I (13.71 ± 1.89 years) than in group II (10.35 ± 3.91 years). However, the time interval between surgery and ambulatory monitoring did not differ between the two groups.

On review of operative reports (Table 3), all seven patients (100%) in group I had ventriculotomy, and four patients (57%) in group I had atriotomy and ventriculotomy. Four patients (21%) in Group II who had atriotomy alone did not develop significant dysrhythmia. One patient (14%) in group I and two patients (10.53%) in group II had transannular patching. Three patients (42.86%) in group I and nine patients (47.37%) in group II had an outflow patch. One patient in group I underwent a second operation.

TABLE 3. Risk factors of significant VA after corrective surgery of tetralogy of fallot (TOF)

Factor	Groupl I	Group II	*P*
Age at surgery (years)	9.14 ± 2.91	5.84 ± 2.20	<0.01*
Age at Holter monitoring (years)	13.71 ± 1.89	10.35 ± 3.91	<0.05*
Interval between surgery and Holter monitoring (years)	4.57 ± 3.46	4.50 ± 4.26	>0.05 (NS)
Duration of cardiopulmonary bypass (min.)	122.14 ± 31.51	111.58 ± 22.83	>0.05 (NS)
Right ventricular (RV) systolic pressure after cardiopulmonary bypass (mmHg)	54.43 ± 11.94	43.50 ± 19.26	>0.05 (NS)
Right ventricular outflow tract (RVOT) gradient (mmHg)	19.00 ± 7.64	19.95 ± 13.12	>0.05 (NS)
Atriotomy	4 (57.14%)	8 (42.11%)	>0.05 (NS)
Ventriculotomy	7 (100.00%)	15 (78.95%)	>0.05 (NS)

*, Significant; NS, not significant.

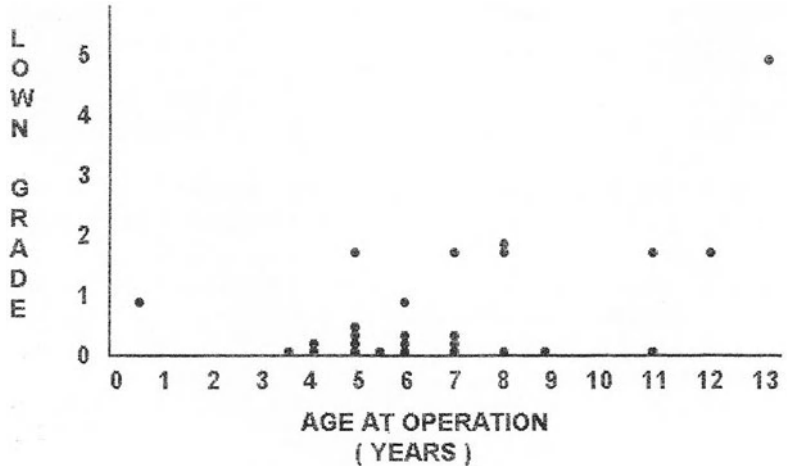

FIG. 1. Relation between age at operation and severity of ventricular arrhythmia using modified Lown's criteria

The duration of cardiopulmonary bypass was more than 100 min in both groups. Right ventricular systolic pressure taken intraoperatively after total correction was higher (54 mmHg) in group I than in group II (43.5 mmHg). Residual ventricular septal defect (VSD) was noted by two-dimensional echocardiography in 4 patients (57%) in group I and in 4 patients (21%) in group II (see Table 3). The RVOT systolic pressure gradient was normal in all 26 patients. Review of the standard 12-lead ECG demonstrated that all patients in groups I and II had complete right bundle branch block. Two patients in Group I showed concomitant premature ventricular contractions.

Discussion

Significant arrhythmia on ambulatory ECG was found in 27% of our patients. This result is lower than those seen in previous reports [11,12]. Rosing et al. [11] noted that 67% of patients showed grade 2 to grade 5 significant ventricular arrhythmia after correction of TOF. Kobayashi and his co-workers [12] also reported that the incidence of VA on ambulatory ECG was as high as 41%. In this study, those with significant VA were older at the time of surgery. The incidence and severity of VA increased with age at surgery, perhaps reflecting progressive fibrotic change in the right ventricle that is submitted to prolonged hypertension at the systemic level [13, 14]. The increase in RV fibrosis with age might result in multiple microentry circuits, which are the substrate for VA [15].

Bove et al. [16] reported that patients with VA are older than those without VA at the time of surgery. Katz et al. [17] also noted that patients who underwent the operation at 30 years of age showed arrhythmia 17 times more frequently than those who underwent surgery at 15 years of age, and patients who underwent correction at 5 years had arrhythmias 1.4 times more frequently than those who underwent surgery at 2 years.

The age at ambulatory monitoring and the time since surgery are slightly increased in group I compared to group II. Patients with significant VA had a longer interval than those without VA. Garson et al. [5] reported that the incidence of VA during exercise testing increased with age at operation and time since operation. It may be said that degeneration of cardiac muscle advances even after surgical repair because of residual ventricular stress such as residual pulmonary stenosis, VSD, and pulmonary regurgitation. Four patients (57%) in group I had residual VSD on two-dimensional echocardiography.

All patients (100%) in group I had a large ventriculotomy as compared to 15 patients (78%) in group II in this study. In patients who underwent TOF correction, the ventriculotomy incision healed to form a linear scar, and it has been found that cardiac muscle cells surrounding the areas of fibrosis have abnormal properties that may lead to localized increased automaticity [18]. The ventriculotomy site may be the origin of a reentrant mechanism for ventricular tachycardia. Atriotomy, which is a new technique in TOF correction, is a preferred approach because it avoids or minimizes the size of the RV scar and preserves RV function. In this study, three patients who had atriotomy had no VA.

Patients with postoperative RV systolic pressure of more than 60 mmHg had a higher occurrence of VA as observed by Gillete et al. [2]. This was likewise observed in six patients (75%) in group I. Garson et al. [5] reported that the incidence of VA

during exercise testing was high in patients with RV pressure of more than 60 mmHg. They also reported that the incidence of sudden death was observed to increase with the elevation of RV systolic pressure. Long-standing elevation of RV systolic pressure was thought to bring about degeneration of cardiac muscle and VA.

The intracardiac repair of TOF carries the risk of damage to the conduction system during cannulation, ventriculotomy incision, and suturing. All patients in this study had complete right bundle branch block (RBBB), which is the most common interventricular conduction defect in repair of TOF. The injury to the right bundle branch may occur along its entire course from its proximal parts in the base of the membranous septum traversing the moderator band to its distal ramification. Vetter et al. [18] found, in 25% of patients with RBBB on post-TOF repair, that right bundle branch conduction was interrupted in the area of the moderator band. Several studies [10,18] have shown that RBBB in these patients has no clinical or hemodynamic consequences. However, RBBB with left-anterior hemiblock should be given particular attention because it can lead to complete heart block. Wolff et al. [6] reported an incidence of 41.7% complete heart block in patients with TOF repair, resulting in a 12.5% incidence of sudden death 6 months to 2 years after surgery.

Conclusion

Among 26 patients evaluated by ambulatory monitoring after repair of TOF, 27% manifested significant VAs. This relatively high incidence of potentially lethal VA, that may be coupled with late mortality suggests that ambulatory monitoring should be a mandatory part of the chronic evaluation of postoperative TOF patients. In this study, two risk factors, namely higher age at surgery and higher age at ambulatory monitoring, were found to be significant. Continued follow-up study is recommended to establish correlation with other risk factors.

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Arrhythmias in Left Isomerism

KAZUO MOMMA and SUMI AIBA

Summary. Three features of arrhythmias in left isomerism are reported. Atrial rhythm is characteristically multiple and tends to slow, corresponding to a poorly developed sinus node in left isomerism. Atrioventricular block, another feature in left isomerism, may present in the fetus. More often, it develops in the first and second decade. The third feature is a dual atrioventricular His' bundle in left isomerism. It was suggested by the presence of two different QRS complexes, corresponding to two atrial rhythms, in four patients with left isomerism. In one case with paroxysmal reentrant supraventricular tachycardia, an electrophysiological study revealed dual AV nodes and His' bundles constituting a reentry circuit for tachycardia, and the posterior His' bundle was successfully ablated with a catheter.

Key words. Left isomerism—Polysplenia—Sinus node dysfunction—AV Block

Introduction

Every mammalian heart develops from a simple tube in the early embryo. Therefore, specialized tissues are distributed as rings at each junction of the primitive heart tube [1,2]. These are the sinoatrial ring, atrioventricular ring, inlet–outlet ring, and ventriculoarterial ring. The presence of these ring-shaped specialized tissues has been shown by phylogenetic studies. Furthermore, the ring concept can be extended to account for ectopic distribution of the conduction system in malformed hearts.

After looping, the trabecular septum and inlet septum develop, and extension of atrioventricular ring tissue is carried on the inlet septum. This specialized tissue becomes a penetrating bundle later, connecting to the early inlet–outlet ring tissue [1,2]. The remainder of the specialized atrioventricular ring tissue largely regresses with development and with ingrowth of the atrioventricular sulcus tissue. By this ingrowth, the atrial myocardial mass is separated from the ventricular myocardial mass. Remnants of the embryonic ring tissue occasionally persist in the margin of the atrial musculature nearest the valve orifice [1,2].

In the definitive heart, the atrial component of the normal system is the atrial node. The node is spindle shaped and is located on the lateral margin of the junction

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between the superior vena cava and the right atrium [1,2]. The atrioventricular specialized junctional area is composed of the transitional cell zone, the compact atrioventricular node, the penetrating bundle, and branching bundles. The AV node is located at the triangle of Koch, which is composed of the tricuspid valve ring, the ostium of the coronary sinus, and the tendon of Todaro.

Atrial Rhythms

In left isomerism, there are morphological left atriums on both sides [1]. Histological studies have shown no sinus node at the junction of the superior vena cava and atrium [3–5]. Ectopic and hypoplastic sinus node has been noticed histologically at the upper lateral wall [3], at the middle lateral atrial wall [4], or at low atrium near the coronary sinus ostium [5] (Fig. 1). More often, it was so hypoplastic that serial histological sections could not identify it [4]. Clinically, a patient with left isomerism usually has associated congenital heart disease such as bilateral superior vena cava, azygos continuation of the inferior vena cava, atrioventricular septal defect, common atrium, pulmonary stenosis, or double-outlet right ventricle [6–8].

We have reviewed the serial electrocardiograms (mean, 9 ECGs per patient) of our 50 patients with left isomerism [9]. Characteristically, multiple atrial rhythm was present in all patients, and two, three, or four different P waves were identified on ECG records [9,10] (Fig. 2). They may be seen in the same record; more often, they were recorded on different occasions. The axis of the P wave was distributed widely and often showed superior orientation, suggesting coronary sinus rhythm [9]. The P-R interval was usually within normal limits. No definite correlation existed between the P-wave axis and the location of the superior vena cava(e) [9].

Another feature of atrial rhythm in left isomerism is slowing of the atrial rate [9] (Fig. 3). A slow atrial rate was present in 20% of infants with left isomerism. With the progression of age, the atrial rate tends to decrease (Figs. 4 and 5). At the age of 15–30 years, 70% of patients with left isomerism show a slow atrial rate (Fig. 4).

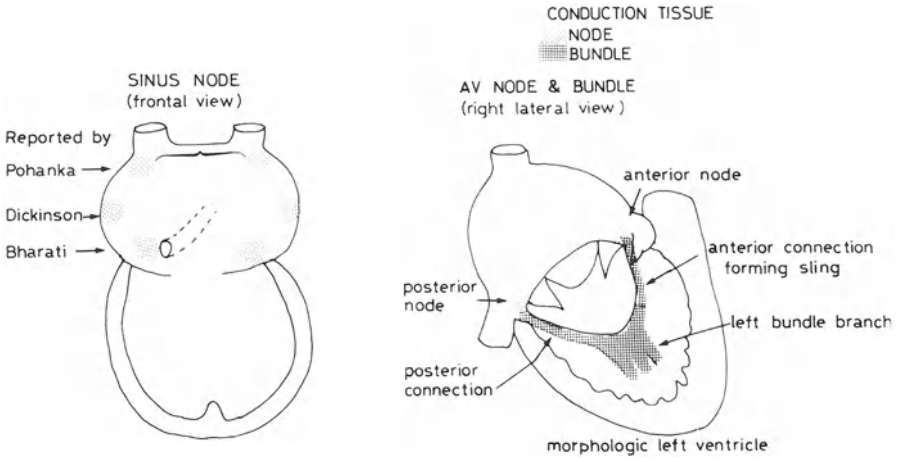

FIG. 1. Distribution of atrial and atrioventricular (AV) conduction tissues as reported in the literature. Frontal atrial view and right oblique ventricular view

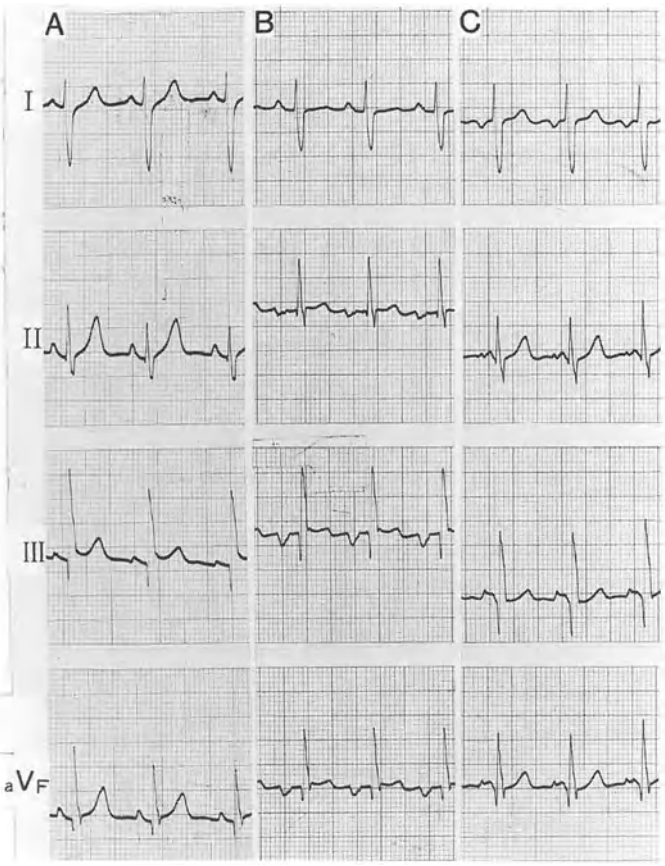

FIG. 2A–C. Multiple atrial rhythms in a 9-year-old boy with left isomerism, bilateral superior vena cava, levocardia, common atrium, common AV valve, single ventricle of right ventricle type, pulmonic stenosis, and azygos continuation of the inferior vena cava. Note three different P waves (*A, B, C*) on three different days. *I, II, III,* and *aVF* indicate ECG leads

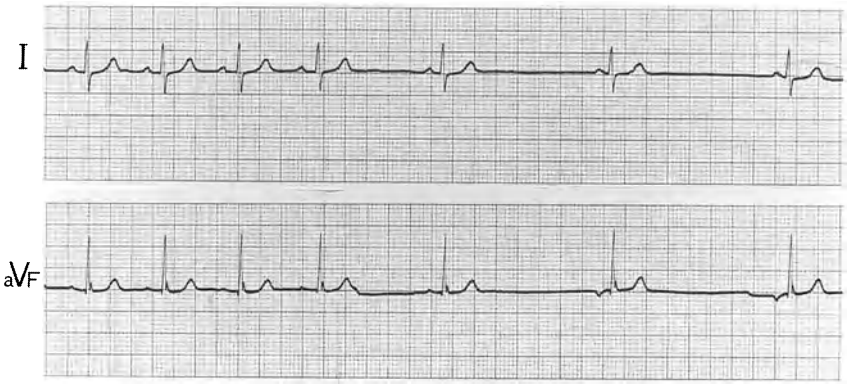

FIG. 3. Slow atrial rhythm in a 13-year-old girl with left isomerism, azygos continuation of the right-sided inferior vena cava, persistent superior vena cava draining to the coronary sinus, and otherwise normal heart. Note slowing atrial rate and changing P wave. I and *aVF* indicate ECG leads

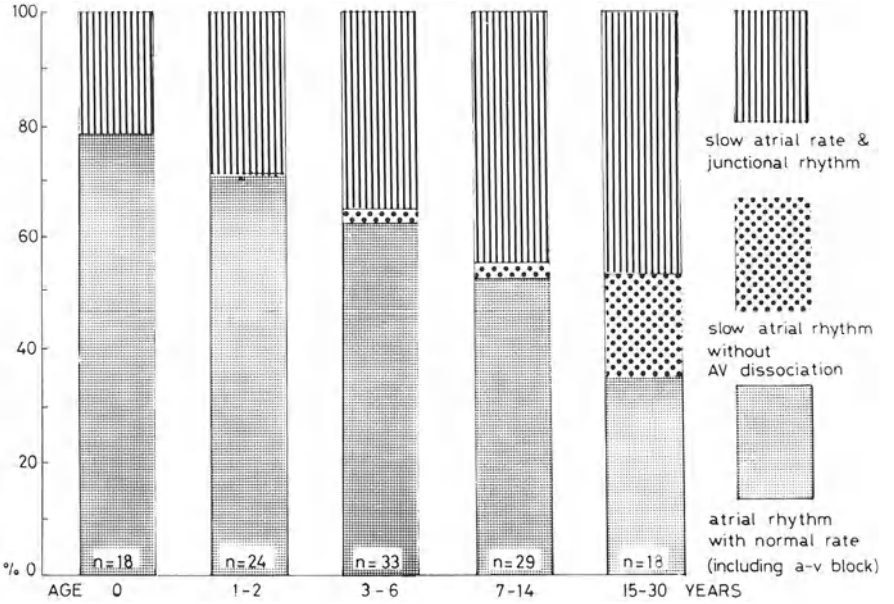

FIG. 4. Atrial rate in left isomerism at different ages. Note progressively popular slow atrial rhythm with advancing age. (From [9], with permission)

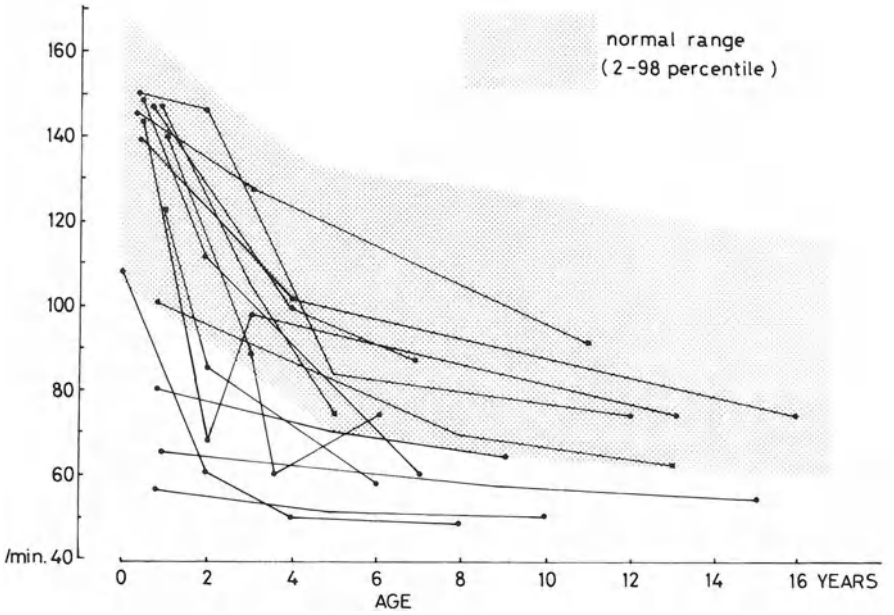

FIG. 5. Atrial rate slowing with advancing age in left isomerism. (From [9], with permission)

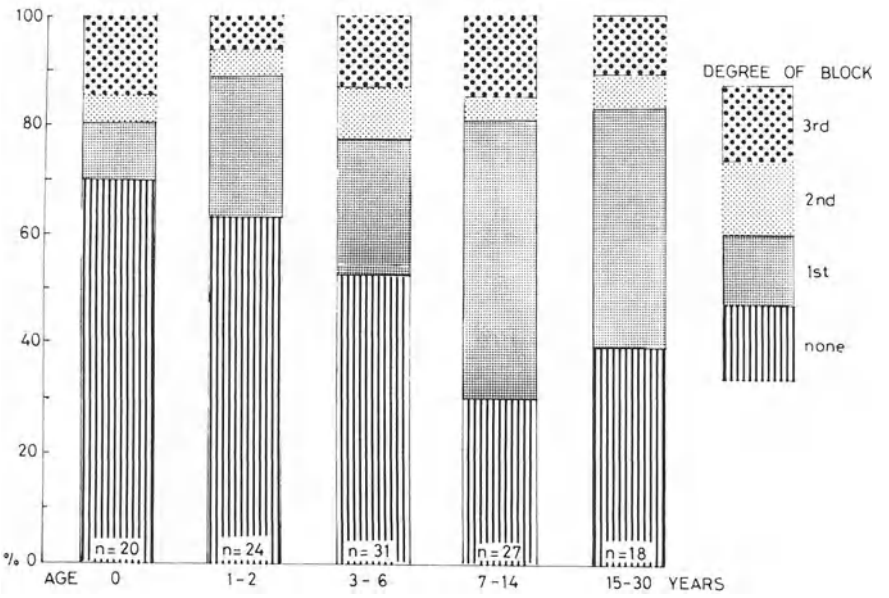

FIG. 6. Atrioventricular block progression as with advancing age in left isomerism. Note more frequent AV block at advanced ages. (From [14], with permission)

Atrioventricular Block

Atrioventricular block in left isomerism has been well documented [11–13]; it may develop in the fetus. In our 50 patients of various ages, 50% of the total showed some degree of atrioventricular (AV) block: first degree, 30%; second degree, 12%; third degree, 8% [14]. AV block is also progressive. Only 30% of infants with left isomerism showed AV block, and 70% of patients aged 7 to 14 had AV block [14] (Fig. 6). Advancement of AV block was documented in 10 patients.

Atrioventricular block in left isomerism is associated with atrioventricular septal defect and atrioventricular discordance (corrected transposition) [15]. An anterior AV node may be present in addition to the usual posterior node [16]. The penetrating bundle may be long and disrupted.

Dual Atrioventricular Conductions

Although this feature has been documented histologically [4], the clinical consequences are poorly understood. We have noted some evidence of the dual atrioventricular connection in left isomerism.

In the study of serial electrocardiograms in 50 patients with left isomerism [9], 3 patients showed distinctly different QRS complexes corresponding to different atrial rhythms. In another 3 patients, junctional rhythms associated with slow atrial rhythm showed different narrow QRS complexes. These findings suggest the presence of dual and separate atrioventricular nodes and His' bundles. We have recently studied another case with left isomerism with dual atrioventricular nodes and His' bundles [17].

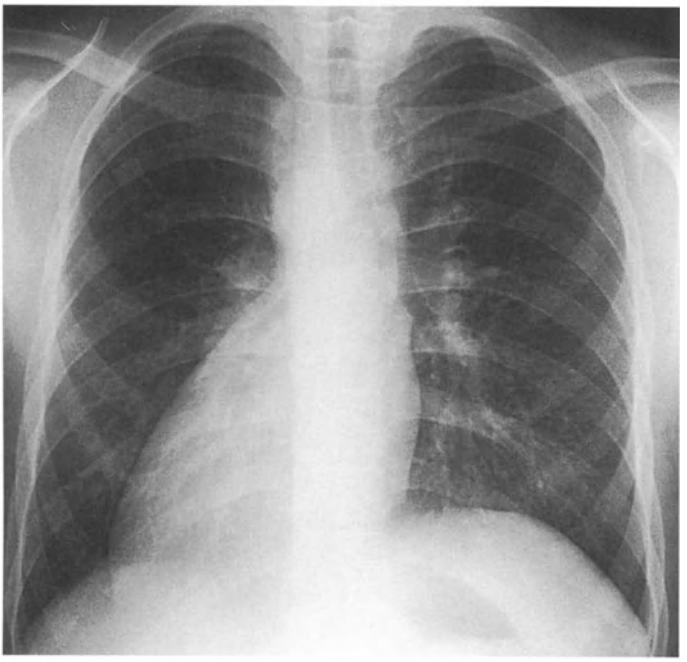

FIG. 7. Chest radiograph of a 13-year-old boy with left isomerism and dual AV nodes and His bundle

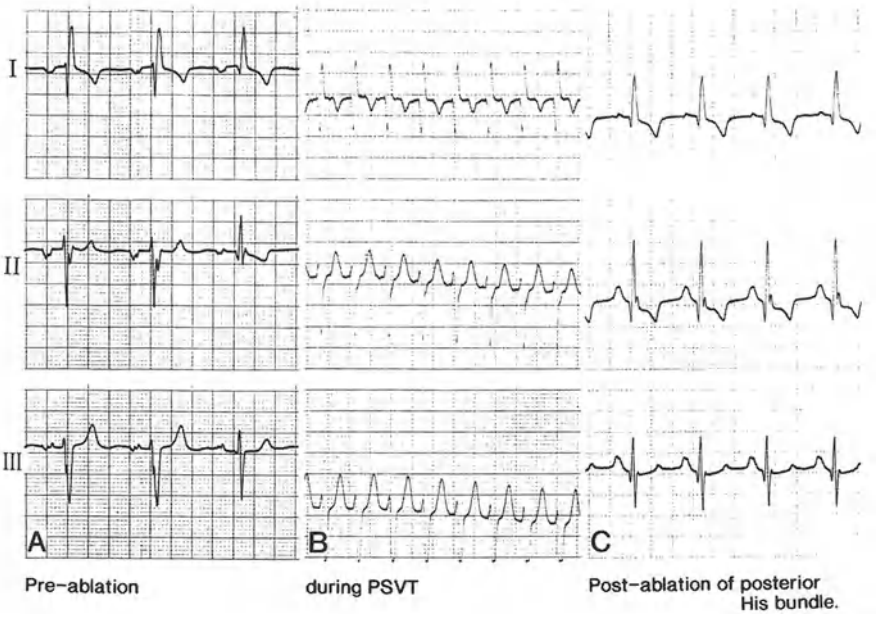

FIG. 8A–C. ECGs of the same patient as in Fig. 7. **A** Two QRS complexes corresponding to two P waves. The first two complexes were conducted through the posterior AV node, and the third complex was conducted through the anterior node. **B** ECG during tachycardia. The QRS complexes shows those conducted through the posterior AV node. **C** ECG following ablation of the posterior His bundle. The QRS complexes show those conducted through the anterior AV node. *PVST*, Paroxysmal supraventricular tachycardia

This case (Fig. 7) is a 13-year-old boy with left isomerism and occassional attacks of paroxysmal supraventricular tachycardia. Cardiac anomalies include dextrocardia (Fig. 7), {A(S),L,L}, bilateral superior vena cava, common atrium and common atrioventricular valve, atrioventricular septal defect (Rastelli type C), double-outlet right ventricle, and pulmonary stenosis. Electrocardiograms showed two different QRS complexes (Fig. 8A). An electrophysiological study revealed posterior and anterior AV nodes and corresponding dual His' bundles [17].

Posterior and anterior atrial stimulation elicited two different QRS complexes, which had been observed previously. Induced and naturally occurring supraventricular tachycardia (Fig. 8B) showed QRS complexes that are the same as those which were elicited by the posterior node stimulation, suggesting that the reentry circuit ran from the atrium to the ventricle through the posterior node and from the ventricle to the atrium through the anterior node. The posterior His' bundle was successfully ablated, and the tachycardic attacks have since stopped (Fig. 8C) [17].

Conclusions

Three features of arrhythmias in left isomerism have been presented. Catheter ablation techniques have advanced and revealed new aspects of therapy in arrhythmias.

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Radiofrequency Catheter Ablation for the Treatment of Cardiac Arrhythmias in Children

MING-LON YOUNG and GRACE S. WOLFF

Summary. From February 1991 to October 1994, 54 children and young adults (13 ± 5 years old or 52 ± 20 kg) underwent 63 sessions of radiofrequency catheter ablation in the Department of Pediatrics, University of Miami. Their arrhythmias included preexcitation syndrome (WPW) (40), atrioventricular (AV) nodal reentrant tachycardia (15), ectopic atrial tachycardia (1), junctional ectopic tachycardia (1), atrial flutter (1), and ventricular tachycardia (2). Nine patients (17%) had significant underlying heart disease. For WPW patients with left-side pathways the success rate was 93% (14/15); the overall success rate for WPW was 80% (32/40). For nonpreexcitation syndrome patients with AV nodal reentrant tachycardia, the success rate was 93% (14/15). The overall success rate for non-WPW lesions was 85% (17/20). Major complications of the ablation procedure included perforation of the heart (1), aortic insufficiency (1), and minor radiation erythema (1). During our 3-year experience we have found certain measures that enhance success, and these are summarized here.

Key words. Cardiac arrhythmia—Radiofrequency catheter ablation—Wolff–Parkinson–White syndrome

Introduction

Radiofrequency catheter ablation has been extensively used in adults for the treatment of cardiac arrhythmias. This procedure has been applied to children in the past few years. To ensure safety and improve efficacy, certain precautions should be taken in performing this procedure [1]. With accumulation of experience, a high success rate and a low complication rate can also be achieved in pediatric patients [2]. Recently, concerns for the risks related to radiation exposure [3–5] and the possibility of radiofrequency lesion growth in small children [6,7] have been raised. However, in comparison to pharmacological treatment [8], radiofrequency catheter ablation can be the treatment of choice in selected children with cardiac arrhythmias.

From February 1991 to October 1994, 54 children and young adults (mean age, 13 ± 5 years; range, 3–24 years; mean weight, 52 ± 20 kg; range, 14–100 kg) underwent 63

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TABLE 1. Results of radiofrequency ablation

	WPW						AVN	EAT	JET	AF	VT	Total
	Total	RFW	RAS	PS	LFW	Mahaim						
Lesions	40	6	7	11	15	1	15	1	1	1	2	60
Success	32	4[a,b]	6[c]	8[b]	14	0	14	1	1	0[d]	1	49

WPW, Wolff–Parkinson–White syndrome; RFW, right free wall; RAS, right anteroseptal; PS, posteroseptal; LFW, left free wall; AVN, atrioventricular nodal reentrant tachycardia; EAT, ectopic atrial tachycardia; JET, junctional ectopic tachycardia; AF, atrial flutter; VT, ventricular tachycardia.

[a] Two patients were successful in the second session.

[b] One patient had two failure sessions for the same lesion.

[c] One patient was successful in the second session.

[d] For AV nodal modification, DC ablation in the third session successfully modified the AV node.

sessions of radiofrequency catheter ablation in the Department of Pediatrics, University of Miami. Nine patients (17%) had significant underlying heart diseases: right ventricular (RV) dysplasia (1), repaired tetralogy of Fallot (2), repaired double-outlet left ventricle (1), hypoplastic RV with modified Fontan procedure (1), dilated cardiomyopathy (2), hypertrophic cardiomyopathy (1), and Ebstein's anomaly (1). The indications for ablation were patient choice (30), drug refractoriness (12), life-threatening arrhythmias (10), and adverse drug reaction (2).

The types of arrhythmias and the ablation results are listed in Table 1. For patients with preexcitation syndrome and left-side pathways, the success rate was 93% (14/15). For all patients with preexcitation syndrome the success rate was 80% (32/40). For patients with atrioventricular (AV) nodal reentrant tachycardia, the success rate was 93% (14/15). Total procedure time averaged 402 ± 132 (range, 160–720) min; total fluoroscopic time was 77 ± 52 (14–190) min. Major complications of the ablation procedure included perforation of the heart (1), aortic insufficiency (1), and minor radiation erythema (1). During follow-up with stress exercise test, Holter, and echocardiogram, there was recurrences in only 4 patients (8% or 4/48 success cases). There were no late complications. During our 3-year experience we have found certain measures that enhance success, and these are summarized as follows.

General Considerations

— Avoid performing radiofrequency (RF) ablation in children with a body weight <15 kg.
— Perform a right heart hemodynamic study before the ablation procedure.
— Have a preablation echocardiogram available for comparison to rule out postablation thrombosis and valvular changes.
— Patients should be heparinized during the procedure with monitoring by activated clotting time. Aspirin 3–5 mg/kg is prescribed for 1–3 months following ablation.
— To better locate the site of ablation, the ablation catheter electrogram should have a low amplification and no voltage cut-off limit.
— Because the catheter movement occurs with respiration, success may be enhanced by performing ablation in shallow breathing, inspiration or expiration, whichever phase provides the ideal and constant electrogram.

Personnel and Facilities

— Double rotatable C-arm cineangiograms equipped with pulsed fluoroscopy are preferred.
— It is desirable that two physicians and two nurses (or technicians) be involved in ablation procedures (preferable to have two experienced physicians who are interchangeable for catheter manipulation and on-line review of tracings).
— Surgical and percutaneous transluminal coronary angioplasty teams should be readily available.
— General anesthesia is preferred for performing ablation procedures in young children.
— Keep a well-stocked catheter cart: regular reach, long reach, short reach, tight curve, braided stiff catheters, etc.
— Allow sufficient time for the ablation procedure.

Minimization of the Radiation Exposure

— Use collimators on the image intensifier.
— Use pulsed fluoroscopy.
— Use right-anterior oblique projection as much as possible.
— Put thyroid shield on the patient.
— Do not perform routine angiogram.
— Protect physicians by a suspended lead shield.

AV Nodal Reentrant Tachycardia Slow Pathway Ablation

— Use His' bundle catheter (2 o'clock position in left-anterior oblique view) and coronary sinus (CS) catheter (5 o'clock position) for orientation in locating the anatomical slow pathway site (4 o'clock position).
— The ablation catheter electrogram shows an A : V ratio of <1 (0.2–0.5) without a His bundle potential.
— Junctional rhythm usually occurs at the successful ablation site. However, if junctional beats occur, use a faster rate atrial pacing to monitor P-R interval during ablation.
— Use low initial RF power setting (15 W) and increase cautiously and progressively to 30 W, observing for AV block.
— Use continuous fluoroscopic monitoring of the catheter position during ablation.
— Map the retrograde slow pathway conduction if it is present.

Preexcitation Syndrome Ablation

— Find the earliest retrograde A or antegrade V activation site with accessory pathway potential (K) and a delta-V interval ≤ 0 ms.
— To better recognize A, K, and V waves, find the pacing cycle lengths that can achieve 2 : 1 AV block with rapid atrial pacing or accessory pathway refractoriness

with atrial or ventricular extrastimulation, thus separating the A wave from the V waves.
— Use decapolar catheter for CS mapping. Record proximal, mid-, and distal CS electrograms; adjust the catheter to allow the earliest depolarization to appear at the mid-CS electrogram, e.g., bracketed by proximal and distal CS electrograms. Then, use the ablation catheter to map around this mid-CS site.
— For right free wall pathway, use braided (stiff) catheter to stabilize the ablation catheter in the AV groove.
— Use "prolapse technique" to advance catheter from the aorta for left-side accessory pathway to avoid aortic insufficiency.
— Use test pulse to reduce RF application time. Stop RF application if accessory pathway block does not occur within 10–15 s.

Ectopic Tachycardia Ablation

— Use mechanical ablation to localize the lesion.
— For atrial tachycardia, find the earliest atrial depolarization at the ablation site with a P-A interval of −30 ms or less.
— Use ablation catheter pace mapping to find the site with a concordant 12-lead surface electrocardiogram P wave.
— Start with a lower ablation power (15 W).

Ventricular Tachycardia Ablation

— Use ablation catheter pace mapping to find the site with a concordant 12-lead surface electrocardiogram QRS wave.
— Find the earliest ventricular depolarization site of the ventricular tachycardia with a Q-V interval of −30 ms or less.

Recent development of a temperature monitoring device for radiofrequency catheter ablation [9] and further refinement of special catheters designed for small children should make pediatric radiofrequency ablation safer and more successful in the future. However, longer follow-up of these patients is needed to assess the long-term safety of this ablation procedure.

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Lessons from the Recent Outbreaks of Rheumatic Fever in the United States

MILTON MARKOWITZ

Summary. After declining in incidence for many years, rheumatic fever had an unexpected resurgence among middle-class children in the United States. The incidence of carditis was unusually high, and was more severe than had been seen in recent years. The most likely reason for the return of rheumatic fever was increased virulence of Group A streptococci and the reappearance of rheumatogenic strains of this organism. It is hoped that the experience gained from this resurgence will contribute to the development of a streptococcal vaccine and to the eradication of rheumatic fever, a major cause of heart disease in many areas of the world.

Key words. Rheumatic fever—Resurgence—Streptococcal infection—Antibodies

In the mid-1980s, there were several outbreaks of acute rheumatic fever in different parts of the United States [1–12]. The reappearance of this disease came very unexpectedly. By 1980, rheumatic fever had become a rare disease in the United States, with a documented incidence as low as 1 case in 200 000 population, about a 50-fold decline since the 1950s [13]. The reasons for this decline included improvement in standards of living, better access to medical care, greater emphasis on the diagnosis and treatment of streptococcal infections, and probably changes in the virulence of these organisms.

The incidence has apparently declined once again to its previous low levels [12]. The purpose of this presentation is to reflect on what we have learned from the experience of these outbreaks.

Epidemiological Features

One of the unusual demographic features of these outbreaks was that many of the patients were white, middle-class children from suburban and rural communities. This is in marked contrast to earlier reports in the United States in which the majority of patients came from crowded urban homes, were poor, and did not have easy access to medical care [13]. Another unusual feature of these outbreaks was that there was no evidence, clinically or epidemiologically, of an increase in group A streptococcal infections in the communities where the outbreaks occurred. This is a reminder that

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children in all social economic groups are potentially at risk for rheumatic fever, even in the absence of any apparent increase in streptococcal infections.

Microbiological Features

The decline in rheumatic fever before these outbreaks occurred even though the number of cases of streptococcal pharyngitis appeared to remain about the same during this period [14]. This raised the possibility that the virulence or "rheumatogenicity" of group A streptococci had diminished in some unknown way druing the period of decline. The concept that streptococci differ in their capacity to initiate an attack of rheumatic fever has been controversial. The resurgence of rheumatic fever provided another opportunity to examine the differences in "rheumatogenic" potential among different strains of group A streptococci.

Strains collected from patients with rheumatic fever or their siblings during the recent outbreaks were found to belong to a small number of serotypes (M-1, M-3, M-5, M-18), all of which had been previously linked epidemiologically to cases of rheumatic fever [15]. Also, studies from the Centers for Disease Control found that M-types 1, 3, and 18 accounted for a larger proportion of the isolates from 1980 to 1988, when compared with isolates obtained between 1973 and 1979 [16]. The reappearance of these serotypes at a time when rheumatic fever returned lends additional support to the concept of rheumatogenicity of certain serotypes or strains within these serotypes of group A streptococci.

The importance of these findings is that the identification of a limited number of such serotypes would greatly facilitate the development of a multivalent vaccine for the prevention of rheumatic fever. The current status of a streptococcal vaccine is discussed later in this chapter.

Clinical Features

The clinical findings among patients in these outbreaks were the classic manifestations of acute rheumatic fever. However, the severity of the attacks was rather striking, especially because rheumatic fever had become a milder disease during the period of decline. In one outbreak, clinical evidence of carditis was found in 72% and congestive heart failure was present in 19%; two of these patients required valve replacement during the acute attack [1].

In the outbreak noted previously, mitral regurgitation was demonstrated by Doppler echocardiography in an additional 19% without clinical evidence of carditis [1]. In a more recent publication, the same authors described their findings in a larger series of patients. In 30 of 53 patients with chorea alone and in 15 of 32 patients with polyarthritis alone, Doppler ultrasonography demonstrated "significant" regurgitation that was not audible [12].

These findings suggest that Doppler echocardiography may prove to be a valuable addition to laboratory techniques for the diagnosis of rheumatic carditis. The authors suggest that silent mitral regurgitation be included as a minor manifestation of the Jones Diagnostic Criteria. However, in the most recent review of these criteria by an American Heart Association committee, it was thought that further investigations are needed because questions have been raised about possible overinterpretation of findings by this method, which could result in "iatrogenic" heart disease [17].

Treatment

None of the reports of the outbreaks described the treatment of the acute attack in the patients. It can be assumed that standard therapy was in use, reflecting the lack of progress in the therapeutics for this disease. Because none of the drugs currently available can prevent rheumatic heart disease from occurring following an acute attack, this is still another reason why better preventive methods are needed.

Prevention

The experience with prevention of recurrent attacks of rheumatic fever was reported in one outbreak with a large series of patients [12]. During the follow-up of 100 patients on oral penicillin to prevent streptococcal infections, 18 developed recurrent attacks of rheumatic fever. This is an unacceptably high rate and emphasizes the need to use intramuscular benzathine penicillin for prophylaxis, the drug of choice recommended by the American Heart Association.

It was surprising that, as many of the patients had medical insurance and ready access to medical care, more of these attacks were not prevented by treating the prior streptococcal upper respiratory infection. The reason for this was that three-quarters of the patients had either no or mild symptoms of an upper respiratory infection and thus had no reason to seek medical care [14]. Therefore, any improvement in our ability to prevent initial attacks of rheumatic fever will require new approaches, such as a streptococcal vaccine.

Work on the development of an antistreptococcal vaccine has been ongoing for a number of years. The three major obstacles in the development of this vaccine are (1) the multiplicity of streptococcal serotypes; (2) the risk of evoking cross-reactive antibodies; and (3) the development of a delivery system that would produce both humoral and secretory antibodies. Major advances have recently been made in attempting to overcome these obstacles, and a streptococcal vaccine appears to be closer to reality than in the past.

Streptococcal M protein is the antigen that stimulates type-specific immunity by evoking opsonic antibodies. Because type-specific antibodies are considered protective, one approach to a streptococcal vaccine would involve incorporation of M antigens corresponding to several distinct type-specific determinants. Unfortunately, more than 80 distinct M serotypes are known, and the development of a universal type-specific vaccine would be a formidable task. Recent evidence suggests, however, that protective although not opsonic antibodies can be produced to conserved, non-type-specific epitopes on the M protein that are shared by many different serological types [18].

In addition to type-specific antibodies, M proteins also elicit other antibodies that cross-react with human myocardial tissue. These other antibodies have given rise to concern that the vaccine itself could injure host tissue. Several groups of investigators have however purified and characterized M protein and succeeded in separating M-protein epitopes that evoke type-specific, opsonic antibodies from M-protein epitopes that evoke heart cross-reactive antibodies [19]. Moreover, chemically synthesized subpeptide fragments of M protein, copying known amino acid sequences of different M proteins, also have been found to be effective immunogens without evoking cross-reactive antibodies [20].

Finally, it has recently been demonstrated that mice orally immunized with an attenuated strain of *Salmonella typhimurium* transformed with cloned M protein were protected against mucosal and parenteral challenge with group A streptococci of the same serotype of M protein as the expressed by the transformed *S. typhimurium* [21]. Work on the development of an oral vaccine for humans that could produce both humoral and secretory immunity to group A streptococci is moving forward, and the availability of such a vaccine in the future appears to be a real possibility [22].

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Should the Gold Standard of Monthly Benzathine Penicillin Prophylaxis for Rheumatic Fever Be Modified?

HUNG-CHI LUE

Summary. The adequacy of monthly benzathine penicillin prophylaxis, the so-called gold standard for secondary prevention of rheumatic fever, was studied. Starting from 1979, 249 patients with rheumatic fever, randomly allocated to a 3-week (124) or 4-week (125) program, were followed until December 1991. Compliance with each program was comparable. Group A streptococcal infections occurred less frequently in the 3-week than in the 4-week program ($P < 0.01$). Prophylaxis failure occurred in 2 of 124 patients (0.3 per 100 patient-years) of the 3-week program, and in 10 of 125 (1.3 per 100 patient-years) of the 4-week program ($P = 0.015$). Of 77 patients with carditis staying in the 3-week program, 47 (61%) lost the mitral regurgitation murmur; of 88 such patients in the 4-week program, 40 (46%) lost the murmur ($P < 0.05$). Our 12-year prospective and controlled study thus revealed that patients on 4-weekly prophylaxis were still at significant risk of rheumatic recurrence with less favorable long-term prognosis. Based on the results of this 12-year study, we recommend, therefore, 3-weekly injections of 1.2×10^6 units of benzathine penicillin G for both chidren and adults with a recent attack of rheumatic fever with carditis. The benzathine penicillin G may be given every 4 weeks in relatively low-risk patients, such as those who had no carditis in the initial attack, who have already lost the murmur, or in whom more than 5 years have passed since the last attack of rheumatic fever.

Key words. Rheumatic fever—Rheumatic heart disease—Streptococcal infection—Benzathine penicillin G

Introduction

Rheumatic fever remains as one of the most important causes of cardiovascular morbidity and mortality [1,2]. Continuous antimicrobial prophylaxis for group A streptococcal infections may prevent recurrences of rheumatic fever [3–6]. An intramuscular injection of 1.2 million units of benzathine penicillin G, monthly or every 4 weeks, has been widely accepted for more than 40 years as the method of choice, a so-called gold standard of secondary prevention of rheumatic fever [4–8]. Most patients

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with a first attack of rheumatic fever can be assured of a good prognosis if they can be maintained on penicillin prophylaxis [9–11].

Prophylaxis failure has occurred, however, during regular monthly prophylaxis [1,6,9,12–18]. Padmavati et al. [17,18] observed, in their retrospective and sequential clinical studies, that 3-weekly penicillin injections had reduced the rate of streptococcal infections and rheumatic recurrences. A pharmacokinetic study by Ginsburg et al. [19] indicated the potential inadequacy of 4-weekly prophylaxis. The World Health Organization and the American Heart Association continued, nevertheless, to recommend 4-weekly prophylaxis in 1988, but added, "The penicillin may be given every 3 weeks in special circumstances or high-risk patients [2,8]." Whether monthly prophylaxis, known as the gold standard, should be modified remains an open question [11, 14, 20, 21].

Our experience of three prophylaxis failures occurring in three patients on monthly prophylaxis prompted us, in 1979, to start randomly allocating all patients with rheumatic fever to either a 3-week or 4-week program [22]. To increase the numbers of patients and of years of follow-up study, and to study the long-term compliance and the outcomes of patients with rheumatic heart disease, we continued the study until December 1991 and found that the prognosis of rheumatic fever patients was better on 3-weekly than on 4-weekly prophylaxis [23]. Based on the results of this 12-year prospective, and a controlled study in a total of 249 patients, the merits of 3-week versus 4-week program were analyzed and are discussed here.

Patients and Methods

From 1979 to 1990, all patients with a history of rheumatic fever at the Department of Pediatrics, National Taiwan University Hospital, were randomly allocated, with informed consent, to a 3-week or 4-week benzathine penicillin injection program. Every patient and their families were instructed by the author (HCL), and given a booklet for recording penicillin injections. Until 1984, patients was examined every 3 to 6 months, or at any time they felt unwell, at the Cardiac and Rheumatic Fever Clinics. Commencing in 1985, all the patients were followed at the Rheumatic Fever Clinic. During 1979 to 1989, throat cultures and sera for antistreptolysin O and streptozyme titers were obtained at the clinic for the monitoring of streptococcal infections. Acute-phase reactants were measured when deemed necessary. Chest X-rays, ECG, and color Doppler echocardiograms were obtained when indicated. Those who missed the clinic were reminded by phone or mail.

Of the 267 patients registered, 7 dropped out and were lost to follow-up, 1 died of drowning, and 10 were proved not to be rheumatic. A total of 249 patients fulfilled the revised Jones criteria and were followed until December 1991, 124 in the 3-week and 125 in the 4-week program. Their age, sex, weight, percentage with previous history of rheumatic fever, cardiac involvement and heart failure, and follow-up duration were comparable. Of these, 230 patients had rheumatic heart disease; 19, of whom 8 had chorea and 11 polyarthritis, had no carditis at entry. Serum samples for the assay of penicillin levels were obtained 1–20, 21, 22–27, 28, and 29–41 days after penicillin injection.

Patient compliance to program was classified as complete if no more than one injection was missed in a year and as partial if two or more injections were missed in a year or a switch was made to oral penicillin or sulfonamide.

Results

Patient compliance with the 3-week and 4-week programs was comparable (Fig. 1). Percentage of positive throat cultures and of elevated antistreptolysin O titers and streptozyme titers in each program was comparable. True streptococcal infections, diagnosed on the basis of two-tube or greater rises of streptococcal antibodies, occurred in both programs: 39 in 520 patient-years in the 3-week (7.5 per 100 patient-years) and 59 in 466 patient-years in the 4-week program (12.6 per 100 patient-years) ($P < 0.01$). Streptococcal infections with no antibody response, so-called carriers, occurred in four and three patients, respectively, in each program.

Nine rheumatic recurrences occurred in 8 patients of the 3-week and 16 in 16 patients of the 4-week program (Fig. 2). Prophylaxis failures occurred in 2 of 124 patients (0.3 per 100 patient-years) of the 3-week and in 10 of 125 patients (1.3 per 100 patient-years) of the 4-week program ($P = 0.15$). Further analysis of the failure rates gave a risk ratio of 5.15 (95% confidence interval = 1.13–23.49), indicating that the 4-week program had a risk of failure as much as fivefold higher than that of the 3-week program.

Assayable serum levels of penicillin were detected in 65% of 343 samples obtained at 1 to 21 days following penicillin injection in the 3-week program: 74% (122/164) during 1–20 days and 56% (100/179) on the 21st day. Such penicillin was detected in 48% of 368 samples obtained at 1 to 28 days in the 4-week program: 68% (91/134) during 1–20 days and 33% (51/155) on the 28th day.

Of the 77 patients with rheumatic heart disease staying in the 3-week program, 47 (61%) lost their mitral regurgitation murmur; their mitral valve on color Doppler echocardiograms appeared completely competent or, in a few cases, showed trivial

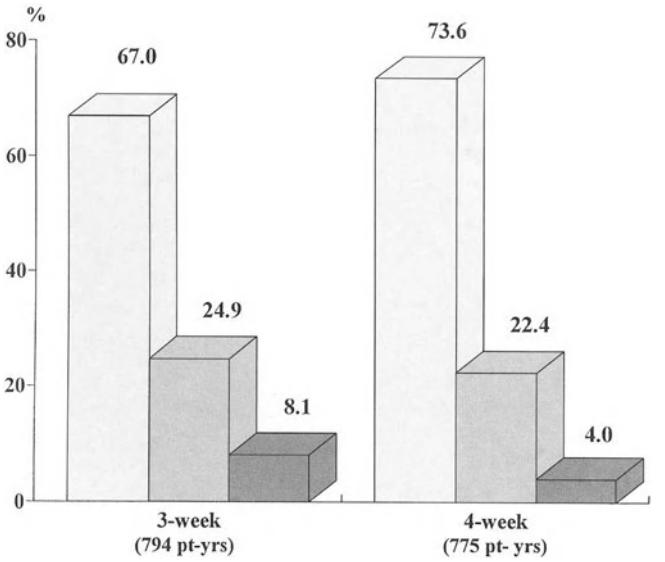

FIG. 1. Patient compliance rates with the 3-week and 4-week benzathine penicillin G programs. The complete (*light bars*) compliance rates, 67.0% vs. 73.6%, and partial (*dark bars*) compliance rates, 24.9% vs. 22.4%, were comparable. *White bars*, Oral administration

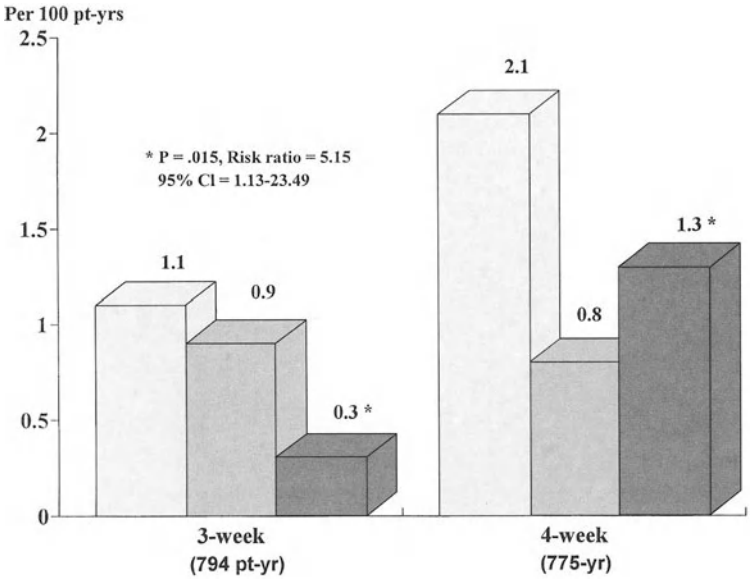

FIG. 2. Rheumatic fever recurrences per 100 patient-years caused by prophylaxis failure (*dark bars*) occurred more often in patients (1.3) placed on 4-weekly benzathine penicillin G prophylaxis, than in those (0.3) on 3-weekly prophylaxis. *, $P = .015$; risk ratio, 5.15; 95% CI = 1.13–23.49. *Light bars*, Noncompliance; *white bars*, total

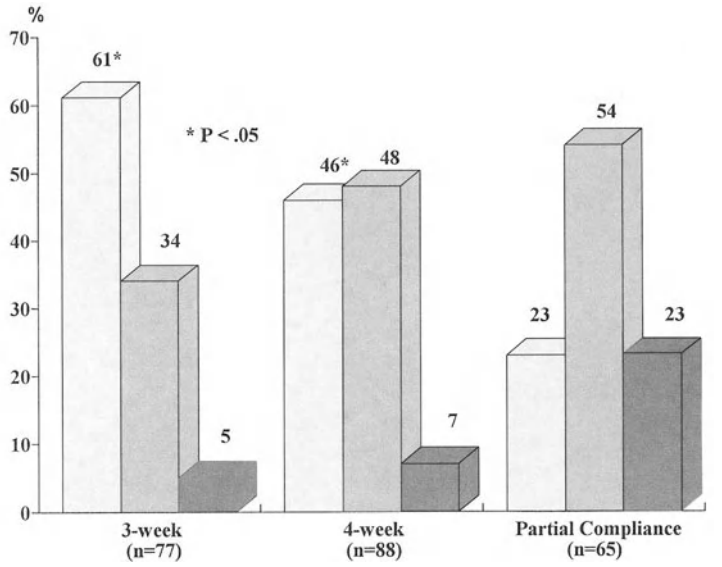

FIG. 3. Outcomes of 230 patients with rheumatic heart disease (RHD) staying on 3-week versus 4-week benzathine penicillin G prophylaxis. Of those on 3-week prophylaxis, 61% lost the mitral regurgitation murmur; of those on 4-week, 46% lost the murmur ($P < .05$); of those partial compliers, only 23% lost the murmur. *White bars*, Mitral regurgitation murmur lost: *light bars*, mild RHD; *dark bars*, moderate to severe RHD

regurgitation (Fig. 3). Four underwent surgery and none died. Of 88 such patients in the 4-week program, only 40 (46%) lost the murmur; 5 underwent surgery and 2 died. Of 65 who were partial compliers, 15 (23%) lost the murmur; 11 underwent surgery and 4 died. A total of 102 patients lost the murmur: 11 (11.8%) during the first year of follow-up 50 (49.0%) in the second to sixth year, 28 (27.4%) in the seventh to tenth year, and 12 (11.7%) during the eleventh year and after.

None of the mitral regurgitation patients staying in the program progressed to mitral stenosis. Aortic regurgitation murmur disappeared in 1 of 32 patients with aortic valvular disease. Of the 19 patients without carditis at entry, 1 chorea case developed a recurrence with carditis and mitral regurgitation. The outcomes for our patients thus clearly correlated with their cardiac status at entry and the regimens of penicillin prophylaxis.

Discussion

Our 12-year concurrent, comparative study documented that the rate of group A streptococcal infections and of prophylaxis failure was lower among patients in the 3-week program than those in the 4-week program, confirming with larger numbers our previous findings that patients on 4-weekly prophylaxis were still at risk of rheumatic recurrence [22,23].

Patient compliance with the 3-week and 4-week programs in our study was comparable, indicating that the added costs for 3-weekly prophylaxis, with five additional injections annually, more travel, and increased workload for medical personnel were not important. Our previous study found that penicillin phobias, pain at injection, cram sessions at school, and shortage of active participation by physicians and health workers were the major causes of poor compliance [12]. Alleviation of such causes should be worked out to promote patient compliance and reduce the rheumatic recurrence rate. Pain and discomfort at the site of injection could be reduced by employment of optimal size needles (#22), and formation of penicillin clots be avoided by increasing penicillin volume from 2.5 to 3.5 ml and delaying injection until the alcohol used has dried (personal observations).

As did Ginsburg et al. [19], Kaplan et al. [24], Raghuram et al. [25], and Decourt et al. [26], we also found an intramuscular injection of benzathine penicillin could not provide effective serum penicillin levels for 4 weeks. The strength and amounts of benzathine penicillin in the preparations used in this study have been checked and proved to be accurate [27].

Bland and Jones [28] observed, before the era of prophylaxis, that 20% of 1000 patients with mitral regurgitation lost the murmur. Tompkins et al. [9] found that 70% of 79 patients with mitral regurgitation, placed on 4-weekly prophylaxis, lost the murmur. The percentage of murmurs lost in the 3-week program here was significantly higher than that in the 4-week program, indicating that 3-weekly prophylaxis was more effective, and that patients on 4-weekly prophylaxis are still at significant risk of rheumatic recurrence.

The World Health Organization recommended, in 1956, monthly injections of 1.2×10^6 units of benzathine penicillin for children and 3-weekly injections for adults, but in 1988 the World Health Organization recommended monthly injections for both children and adults, with 0.6×10^6 units for children weighing less than 30 kg and 1.2×10^6 units for children weighing 30 kg or more and for adults; they added that for

special circumstances or for high-risk patients, the injection may be given every 3 weeks [2,20].

For more effective prophylaxis, 3-weekly and even 2-weekly injection programs have already been tried [29]. Currie et al. [30] tried to elevate serum penicillin levels by increasing the dose of benzathine penicillin to 1.8×10^6 or 2.4×10^6 units.

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Surgery of Valvular Heart Disease: An Update

SHU-HSUN CHU and RON-BIN HSU

Summary. The results of valvular heart surgery have been much improved recently because of improvement in surgical techniques, myocardial protection, and valve substitutes. At the National Taiwan University Hospital between 1965 and June 1994, a total of 3410 patients underwent valvular heart surgery; 2548 had valve replacement and 862 had valvular reconstruction. The operation mortality rates were 9.3% for mitral valve replacement (MVR) and 7.4% for aortic valve replacement (AVR), and have been reduced to 6.4% for both MVR and AVR since 1987. Aortoannuloplasty could be performed in patients with a small aortic annulus who needed AVR, yet without increasing the operation mortality rate. Atrial compartment surgery has recently been performed routinely in addition to valve surgery for patients with chronic atrial fibrillation, with a 60% rate of successful conversion to normal sinus rhythm after surgery.

Key words. Valvular heart disease—Bioprosthesis mechanic valve—Valve replacement—Mitral annuloplasty—Aortoannuloplasty

Introduction

With advancement in myocardial protection during surgery, improved techniques in mitral reconstruction, preservation or restoration of annuloventricular integrity and improvement in valve prosthesis, the surgical risk of valvular heart disease is greatly reduced. The techniques of improved myocardial protection include cold blood cardioplegic solution, warm blood cardioplegic solution, and retrograde blood cardioplegic solution through coronary sinus. An update of valvular heart surgery is presented here based on our experience at the National Taiwan University Hospital.

Experience at the National Taiwan University Hospital

Between 1965 and June 1994, a total of 3410 patients underwent valvular heart surgery at the National Taiwan University Hospital (NTUH). There were 2548 cardiac valve

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replacements and 862 valvular reconstructions. The valve substitutes included biological valves (autograft and allograft), bioprostheses, and mechanical prostheses. The advantages of the pulmonary autograft for aortic valve replacement are good long-term durability and the potential to grow with age. Bioprostheses offer the potential of less incidence of valve-related complications, but their durability and structural deterioration are a matter of much concern. In our hospital during the 1970s, use of a bioprosthesis was more favorable. Since the early 1980s, a mechanical valve has been used more frequently, except in elderly patients.

The operative mortality for mitral valve replacement was 9.3%. It has decreased from 10.3% (93/902) between 1967 and 1987 to 6.4% (21/329) between 1988 and 1994. The operative mortality for aortic valve replacement was 7.4%. It also decreased, from 7.9% (33/418) between 1967 and 1987 to 6.4% (13/203) between 1988 and 1994.

Reoperative valve surgery was performed in 595 patients: a first reoperation in 548, a second reoperation in 43, and a third reoperation in 4 patients. The overall operative mortality rate was 9.9% (59/595): 9.3% for the first reoperation, 13.9% for the second reoperation, and 50% for the third reoperation.

Aortoannuloplasty

For a small aortic annulus, patch enlargement of the aortic annulus was performed in 33 patients. There were 29 aortoannuloplasties, 2 aortomitral annuloplasties and 2 combined aortoventriculoplasty and aortomitral annuloplasty. The overall operatvie mortality for aortic annulus enlargement and aortic valve replacement was 6.1% (2/33).

Thrombolytic Therapy for Mechanic Valve Thrombosis

Between 1993 and 1994, thrombolytic therapy using tissue plasminogen activator was used for mechanical valve thrombosis in six patients. The initial success rate was 83.3% (5/6). One patient underwent emergency thrombectomy 24 h after thrombolytic therapy. Cerebral embolism occurred in one patient and transient femoral artery embolism occurred in another patient during thrombolytic therapy.

Atrial Compartment Surgery

Atrial compartment surgery for chronic atrial fibrillation, commonly present in patients with mitral valve lesion, was performed between July 1988 and February 1994 in 55 patients: 11 with nonrheumatic and 44 with rheumatic heart disease. The rate of conversion to normal sinus rhythm was 60%. The conversion rate was higher in the patients with nonrheumatic heart disease than that in patients with rheumatic heart disease (100% vs 50%). The actuarial survival curve after mitral valve surgery is shown in Fig. 1.

Evolving Procedures

Surgery is evolving for patients with valvular heart disease, especially for those with mitral regurgitation, because of the increasing adoption of valve repair techniques [1].

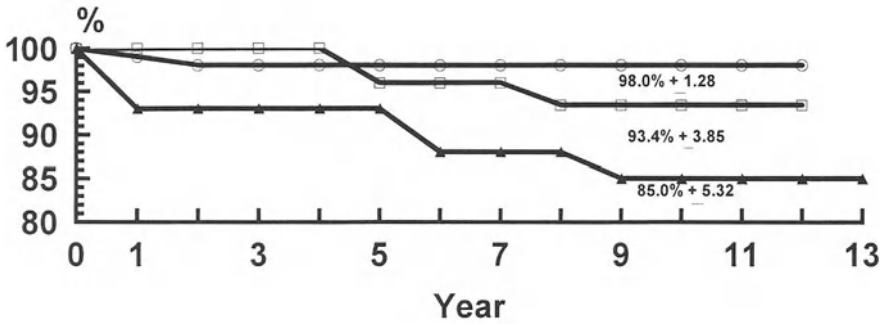

FIG. 1. Actuarial survival after mitral valve surgery. MAP (*circles*), Mitral annuloplasty; MC (*squares*), open mitral commissurotomy; MVR (*triangles*), mitral valve replacement

The advantages of valve repair over valve replacement are less need for anticoagulation, a lower incidence of infective endocarditis, and retention of the mitral subvalvular apparatus [1–3]. For mitral regurgitation with excessive valve motion, surgical techniques available are quadrilateral resection, chordal shortening, and chordal transfer. For mitral stenosis with restricted motion (especially in rheumatic heart disease), available surgical techniques are commissurotomy, fenestration or splitting of fused chordae, removal of fibrous peel, and debridement of calcification. With the increasing use of valve repair rather than replacement, the indications for surgical intervention have changed, and more patients are undergoing valve repair at an earlier stage of illness [4].

Reoperation

Reoperative valve surgery for structural deterioration of a bioprosthesis has increased in frequency, particularly in the elderly [5–7]. Reoperations are technically more difficult because of the adhesive process around the heart and the association with pulmonary hypertension. In the early years, reoperative valve surgery had a higher operative morbidity and mortality than the primary valve operations. Reductions in reoperative risks have been achieved by the introduction of new surgical techniques and improved cardioplegic myocardial protection. The surgical techniques include limiting dissection to the ascending aorta and the right atrium (RA) for aortic valve rereplacement, dissection extended from the RA to just over the interatrial groove for mitral valve surgery, and single RA cannulation for venous return. Superior and inferior venae cavae and left and right ventricles are not dissected. These new techniques reduce the postoperative bleeding and shorten the operation time. Early institution of partial cardiopulmonary bypass helps to prevent and manage the injury to the dilated right ventricle while the chest is being reopened. In our series, the overall mortality rate for reoperative valve surgery was 9.9%.

Progress in Valve Substitutes

The major advances in valve replacement are the progresses made in valve substitutes [4,8]. The resurgence in popularity of an aortic homograft has resulted from the development of cryopreservative techniques for these valves. The aortic homograft

and pulmonary autograft are superior to bioprosthetic valves in terms of their durability, the hemodynamics attained, and the obviation of anticoagulation. However, their use requires greater surgical expertise and an operation of longer duration.

Although the development of prosthetic valve designs is continuing, manufacturers have been slow to release new prostheses because of the stringent guidelines that prevent premature marketing of possible faulty prostheses. The aortic homograft and pulmonary autograft are being used increasingly, especially in young patients with aortic valve disease.

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Prevention of Infective Endocarditis: Reconsidering the Facts in the 1990s

EDWARD L. KAPLAN

Summary. Antimicrobial prophylaxis for prevention of bacterial endocarditis remains a very controversial issue. Whether this is a tradition or a necessity has been called into question. However, logic dictates that as one can apparently reduce both qualitatively and quantitatively the bacteremia associated with certain dental and surgical procedures, and because bacteremia appears to be an important risk factor, it remains appropriate to administer antimicrobial agents to most at-risk patients with underlying cardiovascular disease.

Key words. Bacterial endocarditis—Prophylaxis—Bacteremia—Prevention

Introduction

There are few more controversial issues in the practice of medicine and dentistry than those surrounding the efficacy and the necessity for prevention of bacterial endocarditis by the use of prophylactic antibiotics. Although there have been numerous studies demonstrating that becteremia can result from dental and surgical procedures and studies showing that the incidence of bacteremia may be reduced if appropriate doses of antibiotics are administered at the time of a dental or surgical procedure, there have been no controlled studies which demonstrate conclusively that one can prevent the occurrence of endocarditis with antimicrobial prophylaxis. Furthermore, it has been shown that prophylaxis failures do occur even when adequate doses of appropriate antibiotics have been administered [1]. These facts have led to skepticism by some, who suggest that perhaps more individuals have been harmed than have been protected by the administration of these antimicrobial agents.

Evaluation and Judgment

It is the purpose of this brief review to examine some of these controversies surrounding prophylactic antibiotics for prevention of infective endocarditis and to examine how these dilemmas affect children with underlying cardiovascular disease in the mid-1990s. It should be pointed out, however, that there are no guidelines which can

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completely replace the physician's thoughtful evaluation and judgment when faced with the issue of providing prophylaxis for prevention of bacterial endocarditis.

Initial recommendations for guiding physicians and dental practitioners were issued several decades ago, and these have changed remarkably during the past three or four decades. These changes came as the result not only of careful clinical and epidemiological observations, but also were stimulated by the development of reliable animal models for studying prevention and therapy of bacterial endocarditis in the early 1970s. Since that time, prophylaxis regimens have been formulated in many countries around the world and all have tended to become simpler, more convenient for practitioner and patient alike, and therefore perhaps more cost effective.

Review of the literature shows clearly that although there are some instances when infective endocarditis develops without the presence of underlying cardiovascular disease, the very large majority of cases occur in patients with structural cardiovascular pathology. Specifically, a pressure gradient, usually one with a resulting jet lesion, is a required predisposing factor. Lesions without pressure gradients (e.g., secundum atrial septal defect) rarely, if ever, are the anatomical site for endocarditis. It has been shown that a jet across the pressure gradient leads to injury of the endothelium or endocardium. This disruption is followed by the laying down of fibrin and platelets, forming a meshwork that ultimately can trap circulating microorganisms and provide the nidus for the infection.

Thus several of the risk factors that lead to vulnerability of individual patients appear obvious. However, there also are data suggesting that the magnitude of the bacteremia and the tropism of the infecting organism may influence the ultimate development of a vegetation. A "large dose" of bacteria (perhaps as high as 10^7 organisms) may be required to cause infection under these conditions.

Underlying Cardiac Conditions

In most countries, patients with cogenital heart disease are the largest group of patients in the pediatric age group who develop endocarditis. However, it must be remembered that in many countries of the developing world, countries where the prevalence of rheumatic valvular heart disease remains very high, this latter category of patients appears to constitute a majority of the affected patients.

Among those individuals with congenital heart disease, the highest risk appears to be those with cyanotic lesions such as tetralogy of Fallot. The risk seems to be enhanced by the presence of surgically constructed systemic-artery-to-pulmonary-artery shunts. Patients with aortic valvular stenosis, particularly those associated with insufficiency, are also at high risk, as are patients with prosthetic heart valves. Patients with mitral valve prolapse, again especially those with regurgitation, frequently appear in series of pediatric and adult patients with endocarditis. Whether this is due to the absolute risk or simply to the fact that there are a very large number of patients with this lesion continues to be argued.

There are some patients, such as those with ventriculoatrial shunts to relieve hydrocephalus, immunocompromised patients, or patients with normal valves who are intravenous drug abusers, who also appear to be at risk to develop endocarditis; however, prophylaxis is not always relevant to these groups of individuals. Although cases of infective endocarditis have been reported in immunocompromised patients and in cardiac transplant patients [2], the risks appear to be low even though compre-

hensive studies are not available. Similarly, ill patients with indwelling lines, such as young neonates, also appear to be at risk, but the exact risks have yet to be completely defined [3].

Controversies

Recently a thoughtful but not universally accepted examination of the efficacy of antibiotic prophylaxis was published by Wahl [4]. While there certainly will not be uniform agreement with the position he has taken, his considered point of view does stimulate an evaluation of this admittedly controversial area. The author describes nine "myths" (or perhaps they should be called controversies) about infective endocarditis prophylaxis. Review of these nine points (Table 1) offers the opportunity to examine the efficacy and clinical utilization of endocarditis prophylaxis.

While it is beyond the scope of this limited review to go into each of these points in detail, several deserve special comment. It is quite clear from published studies that compliance by physicians, dentists, and patients often is suboptimal. There are published reports showing an unexpectedly small percentage of practitioners, both dental and medical, who actually comply with recommendations. This is somewhat surprising in view of the educational programs written and undertaken by professional societies to educate both practitioners and their patients.

There also are published data suggesting that even where there appears to be an oral origin for the bacteremia, this frequently is not just temporally related to dental procedures, but rather associated with poor dental hygiene. Furthermore, a dental procedure can be confused because visits to the dentist are probably the most frequent procedure that patients undergo and it is not difficult to temporally relate the onset of endocarditis to a dental visit.

Antimicrobial prophylaxis, while theoretically more effective now than in the past, does not provide total protection. There are clearly documented examples of prophylaxis failures, although most of these occur in patients who received inadequate or unconventional doses of antimicrobial agents [1].

Other controversies relate to appropriate antibiotics and appropriate doses and whether parenteral antibiotics are preferable to oral antibiotics. The issue of mitral valve prolapse continues to remain controversial, although less so now than perhaps

TABLE 1. Myths/controversies about bacterial endocarditis prevention

Myth 1. There is general awareness of and compliance with recommendations for prevention of endocarditis.
Myth 2. Most cases of infective endocarditis originating from the oral cavity have a dental origin.
Myth 3. Recommended antibiotics for prevention give total protection against endocarditis.
Myth 4. Antibiotics should be given for procedures that cause bleeding (gingival).
Myth 5. If a patient is receiving an antibiotic at the time of a procedure, there is no need to change the drug/dosage.
Myth 6. The risk of endocarditis with procedures is almost always greater with the procedure than is the risk of an adverse drug reaction.
Myth 7. Parenteral antibiotics are almost always preferable for "high-risk" patients.
Myth 8. All patients with mitral valve prolapse should receive prophylactic antibiotics.
Myth 9. In some countries: Clinicians should err to the side of giving too much antibiotic to prevent the possibility of a lawsuit

Modified from [4].

a decade ago. For example, one study [5] has shown that classical mitral valve prolapse with redundant leaflets is more often responsible for endocarditis rather than is simple mitral valve prolapse without mitral regurgitation. This is among the facts that lead to changes in recommendation; thus, only in instances of documented mitral valve regurgitation are prophylactic antibiotics now recommended.

Recommendations

In view of these remaining important clinically relevant controversies, what advice can be given to practitioners? Many cardiac societies and heart associations have formulated recommendations [6]. These may differ to some degree, but generally speaking they are quite similar. The general principle, although there are exceptions, is that those patients who remain at risk to develop endocarditis because of the anticipation of bacteremia following a dental or surgical procedure should receive appropriate antibiotics, which should be directed to those organisms most likely to cause endocarditis. Although staphylococci have recently assumed a larger role in causing infective endocarditis than in the past, alpha-hemolytic streptococci and enterococci remain the organisms most frequently isolated in patients with endocarditis. Antimicrobial prophylaxis is directed against these organisms [6].

Agreement exists that oral antimicrobial agents are usually effective and parenteral administration is indicated only in special circumstances, such as when patients are unable to take an oral medication or when, for example, the patient requires general anesthesia for a specific dental or surgical procedure. Intravenous antibiotics can be given with little trouble.

Modifications of recent recommendations by the American Heart Association for specific antibiotics to be used in commonly performed dental and surgical procedures are available and are not reproduced here [6]. Other societies have similar recommendations; many have suggested only a single dose of oral amoxicillin for dental procedures, but the American Heart Association has recommended a second dose 6 h following the initial one. Likewise, although erythromycin was the only alternative in the past for patients who were allergic to penicillin, clindamycin has become an acceptable alternative. Recalling the difference in the definition of prophylaxis and treatment, one must recognize that antimicrobial prophylaxis for the prevention of bacterial endocarditis is a short-term administration which can be of importance in the overall management of children with cardiovascular disease.

The emergence of resistant enterococci has made prophylaxis for genitourinary and gastrointestinal procedures a more complicated task. For these reasons, most authorities have not recommended orally administered antibiotics to patients with gastrointestinal or genital urinary tract infections. Decisions about specific antibiotic agents should also be influenced by the clinician's understanding and knowledge of current antibiotic resistance patterns in a given hospital or community. Thus, antibiotic prophylaxis for prevention of endocarditis requires more than simply consulting a set of guidelines.

Pediatricians have a number of unique problems when faced with decisions regarding infective endocarditis antimicrobial prophylaxis. There are very few, if any , data to indicate whether antimicrobial prophylaxis is required for procedures commonly performed in children, such as tympanostomy tubes, simple urinary bladder catheterization, circumcision, and endotracheal intubation under controlled circumstances.

From a practical clinical approach, it is best to consider the underlying cardiac condition; in those instances in which a relatively high risk is present, many pediatricians and pediatric cardiologists do recommend antimicrobial prophylaxis.

It should be mentioned that in many developing countries of the world, infective endocarditis is different from the point of view of infecting organisms as well as underlying cardiovascular disease. Published series suggest that viridans streptococci remain much more common than staphylococcal infections and that antimicrobial resistance patterns may be very different, depending on the patterns of use of antibiotics. Special consideration also is required in these circumstances.

There are reports of well-designed studies suggesting that oral degerming with appropriate mouthwashes is an effective adjunct in preventing bacteremia following certain dental procedures [7]. These studies are infrequently mentioned, but have particular relevance to pediatric patients. Although this technique cannot be used alone, in certain patients, for example, pediatric patients wearing orthodontic appliances, this precaution can reduce the bacterial count in the oral cavity and thus very likely reduce the incidence of bacteremia. This technique can be effective and should be considered in appropriate clinical circumstances.

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Surgery of Pediatric Infective Endocarditis: An Update

ZEN-CHUNG WENG and SHIAU-TING LAI

Summary. Recent advances in cardiac surgery have increased the likehood of survival in pediatric patients with infective endocarditis (IE). However, controversy still exists with regard to the indications as well as the timing of surgery in patients with active disease. This retrospective study summarizes our surgical experience with IE in children during the past 12 years, with an attempt to set up current guidelines for operative therapy. From January 1981 to December 1993, 21 children with IE were treated surgically. All except one infant had underlying cardiac lesions. Eighteen patients (86%) had associated congenital heart defects, and 2 patients had rheumatic heart disease with mitral regurgitation. *Staphylococcus aureus* and *Streptococcus viridans* were the most common infecting organisms. Urgent operations were performed on 9 patients, and 12 patients underwent elective surgery. There were three deaths in this series: two deaths were of patients who underwent concomitant repair of complex congenital heart disease and one death was that of a 3-month-old infant with a normal heart. The overall mortality rate was 14.3%. Although all the mortality occurred among the patients who received urgent operation for IE, satisfactory valve repair instead of valve replacement was only feasible for those patients whose operative procedures were performed on an urgent basis. In conclusion, surgery of IE in children still carries high risks, especially in patients with complex congenital heart disease. However, to prevent serious complications of IE, early surgical intervention before the onset of hemodynamic deterioration should be encouraged.

Key words. Infective endocarditis—Surgery—Vegetation—Valve repair—Valve replacement

Introduction

Infective endocarditis (IE) in children is a relatively rare but often devastating disease that causes significant morbidity and mortality even when treated with effective antimicrobial agents. The majority of cases of IE in children, approximately 70%, are associated with congenital heart defect [1–3]. Without surgical treatment, most of the

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morbidities and mortalities of IE are associated with the complications of infection, such as progressive heart failure or uncontrolled infection with embolic events [4]. The role of surgery in the management of pediatric endocarditis has evolved in recent decades and supports an aggresive surgical approach to pediatric IE. However, consensus is still lacking regarding the indications for and optimal timing of operative intervention in pediatric IE. The purpose of this retrospective study is to analyze our surgical experience with pediatric IE in 21 children, with special emphasis on the relation between the timing and the outcome of surgery of pediatric IE.

Patients and Methods

Patient Population

From January 1981 to December 1993, 21 children under 18 years of age who were admitted to Veterans General Hospital—Taipei were operated on for infective endocarditis. There were 12 boys and 9 girls whose mean age at operation was 13.5 years (range, 3 months to 18 years). A retrospective review of the hospital chart, laboratory reports, pathology reports, and echocardiogram reports were undertaken for each patient.

Diagnosis of infective endocarditis was made on the basis of one of the following: (1) positive blood culture and new or changing cardiac murmur, (2) positive blood culture and a known preexisting cardiac lesion with persisting fever, splenomegaly, and heart failure, (3) positive blood culture and a known cardiac lesion with persisting fever of unknown origin, (4) negative blood culture and a known cardiac lesion with persisting fever and echocardiographic evidence of vegetations, and (5) negative blood culture and a known cardiac lesion with embolic phenomena.

Clinical Characteristics

In Table 1 are summarized the clinical symptoms and signs observed among 21 patients during admission. Most of these patients presented with fever and general weakness. Congestive heart failure was evident in 4 patients. Fourteen patients had

TABLE 1. Clinical symptoms and signs of 21 patients with infective endocarditis

Symptom and sign	No. of patients	%
Fever	21	100
Pallor	12	57
Weakness	15	71
Hepatomegaly	7	33
Splenomegaly	5	24
CNS infarction	4	19
Petechia	4	19
Arthritis	3	14
CHF	4	19
Pulmonary embolism	2	10
Janeway lesion	1	5
Osler's node	1	5

CNS, Central nervous system; CHF, congestive heart failure.

echocardiographic evidence of vegetations, which involved the mitral valve in 5, tricuspid valve in 4, aortic valve in 4, and pulmonic valve in 2 patients, respectively. The youngest patient with a vegetation, which was detected in the right atrium, was a 3-month-old premature infant on total parenteral nutrition therapy through a central venous line. All except this infant had an underlying cardiac lesion: 18 (86%) had a congenital heart defect, and 2 had rheumatic heart disease with mitral regurgitation.

Ventricular septal defect (VSD) was the most common congenital heart defect (five cases); mitral regurgitation (MR) of either congenital (five cases) or rheumatic origin (two cases) was the most common preexisting valvular lesions. The remaining underlying cardiac lesions are shown in Table 2.

Microbiology

The infectious organisms isolated before or during surgery from 15 patients are summarized in Table 3. *Staphylococcus aureus* (4 cases) and *Streptococcus viridans* (5 cases) were the most common organisms. Culture was negative in 6 cases. The possible sources causing bacteremia and then endocarditis in our patients are summarized in Table 4. Upper respiratory infection was most common, occurring in 8 patients (38% of total cases). No apparent source could be identified in 4 patients.

Surgical Indications and Procedures

Nine patients underwent surgical intervention during the active phase of infection, or before the completion of the full course of antimicrobial therapy. Indications for urgent operation were uncontrollable infection, progressive heart failure, systemic or pulmonary embolization, and large and mobile vegetations detected by echocardiography. The remaining 12 patients underwent elective operation, after a complete

TABLE 2. Underlying cardiac lesions

Cardiac lesions	No. of patients
VSD	5
MVP + MR	3
ASD + MR	2
RHD + MR	2
PDA	2
TOF	2
CAVC	1
TAPVR	1
COARC	1
AS	1
Normal heart	1

VSD, Ventricular septal defect; MVP, mitral valve prolapse; MR, mitral regurgitation; ASD, atrial septal defect; RHD, rheumatic heart disease; PDA, patent ductus arteriosus; TOF, tetralogy of Fallot; CAVC, complete atrioventricular canal; TAPVR, total anomalous pulmonary venous retum; COARC, coarctation of aorta; AS, aortic valve stenosis.

TABLE 3. Infectious organisms isolated

Organisms	No. of patients	%
Streptococcus viridans	5	24
Staphylococcus aureus	4	19
Staphylococcus epidermidis	2	9.5
Streptococcus pneumoniae	1	5
Pseudomonas ceparis	1	5
Enterobacter sp.	1	5
Candida sp.	1	5
No growth	6	28.5

TABLE 4. Possible causes of bacteremia

Cause	No. of patients	%
URI	8	38
Skin infection	4	19
Dental caries	2	9.5
Meningitis	1	5
Wound infection	1	5
Central venous line	1	5
Unknown	4	19

URI, Upper respiratory tract infection.

TABLE 5. Operative procedures performed

Procedures	No. of patients	Underlying cardiac lesions
Resection of vegetation	1	Normal heart[a]
Resection of vegetation and pericardium closure of VSD	4	VSD (4)
Resection of vegetation and closure of ASD and repair of mitral valve	2	ASD + MR (2)
Resection of vegetation and mitral valve replacement	4	PMV + MR (2) RHD + MR (2)
Mitral valve repair	1	PMV + MR
Resection of vegetation and total correction of TOF	1	TOF
Total correction of TOF	1	TOF
PDA ligation	1	PDA
Coarctation repair	1	COARC
Aortic valve replacement	1	AS
Total correction of TAPVR	1	TAPVR[b]
Total correction of CAVC	1	CAVC[c]
PDA ligation, aortic valve replacement, and closure of aota-to-right-atrium fistula	1	PDA
Closure of VSD and pulmonary valvectomy	1	VSD

[a] In-hospital death from sepsis of abdominal origin.
[b] In-hospital death from relapsing pulmonary infections.
[c] In-hospital death from low cardiac output from imperfect repair.

course of antibiotic therapy, for the repair of underlying cardiac lesions or of valvular and related lesions caused by endocarditis.

Operative procedures performed in our patients are listed in Table 5. Resection of the vegetation was performed in our youngest patient, who developed fungal endocarditis from central venous line sepsis. Resection of the vegetations and closure of

VSD with autologous pericardium were performed in four of five children with VSD. Pulmonary valvectomy was performed as an additional procedure in the remaining one VSD patient, whose pulmonic valve was damaged by endocarditis and possibly also by the jet of shunt flow through the subpulmonic VSD. Resection of the vegetations and mitral valve replacement with a mechanical prosthesis were performed in four children with MR. In the remaining three patients with MR, mitral valve repair only was performed.

In one female patient with PDA, the aortic valve was damaged with an aorta-to-right-atrium fistula formation; PDA ligation, aortic valve replacement, and closure of the aorta-to-right-atrium fistula with autologous pericardium were performed during the active phase of the disease. Three other procedures performed on an urgent basis were intracardiac repair of tetralogy of Fallot (two cases), repair of total anomalous pulmonary venous return (one case), and repair of complete atrioventricular canal (one case). Concomitant resection of the vegetations over the right ventricular outflow tract and pulmonic valve was also performed in the child with Fallot's tetralogy. In the patient with aortic stenosis, the thickened bicuspid aortic valve together with vegetations was excised and replaced with a 19 mm St. Jude mechanical valve (St. Jude Medical, Inc., St. Paul, MN, USA).

Results

There were three deaths in this series. One death was that of the 3-month-old infant with normal heart because of sepsis. Another infant with total anomalous pulmonary venous return (TAPVR), complicated with pulmonary emboli, died of relapsing pulmonary infections following TAPVR intracardiac repair. Another death was that of an infant with complete atrioventricular canal after intracardiac repair of the canal and mitral valve. All these three fatal cases were among the nine patients who received urgent operations for IE. The mortality rate of urgent operations for IE was 33% (3/9), significantly higher than that of elective operations for IE. The overall mortality rate in our series of patients was 14.3%. All the survivors were followed-up from 11 months to 13 years. All did well and remained in NYHA functional class I.

Discussion

Despite the great advances in cardiac surgery, surgical intervention in infective endocarditis in children still carries a high risk. Review of the recent literature revealed that the mortality rate ranged from 14% to as much as 50% [5–7]. Most of the deaths were associated with complex congenital heart disease, for which operative interventions were often delayed and considered as a last desperate effort. Of the three deaths in our series, two deaths were those of patients with complex congenital heart disease (TAPVR in one and CAVC in one).

However, an even higher mortality of 85% has been reported in nonsurgical patients with moderate to severe heart failure. Richardson et al. [5] reported a mortality rate of 44% among patients receiving medical treatment of IE as opposed to a 14% mortality in a comparable surgically treated group of patients. Aslamaci et al. [8] reported that the operative mortality in NYHA class IV patients was 23%, while it was only 4% in class III or II patients, and emphasized the need of early operation. In view of these findings, we surmise that timing of the surgery should be decided on the basis

of the hemodynamic status of the patients instead of the infective state. That is, surgical intervention should be instituted at the time when the patient first presents with signs of heart failure, even during the active phase of infection.

It is worth mentioning that all the elective operations for valvular lesions required valve replacement, because the valves were very much thickened and rolled by the prolonged infectious processes, as described by Hovath et al. [9]. In contrast to this, valve repair was possible in those patients who underwent urgent operations for IE. We used the pericardium as an autologous patch for valvular reconstruction and had sastisfactory results, as has been reported by others [10–12]. Valve replacement in children poses many unsolved problems, such as the growth potential of the children and the requirement of lifelong auticoagulation; thus, every possible valve-conserving measure should be seriously considered when dealing with pediatric IE with valvular lesions. Our limited experience and that of other investigators [13,14] emphasizes the need of early operation.

Conclusion

We report our limited surgical experience with IE in children. Overall surgical mortality was 14.3%, higher in children with underlying complex congenital heart disease. Early surgical operation before the onset of hemodynamic deterioration is encouraged. If properly executed, aggresive and early surgery may prevent the serious complications of IE.

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