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SPORTS CARDIOLOGY

Exercise in health and cardiovascular disease

edited by

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Foreword

Participation in athletics at both the recreational and competitive levels has grown enormously over the last decade, and now involves a substantial segment of the population of many countries, particularly those in Europe and North America. This change in the life-style of many individuals has been accompanied by the desire and necessity on the part of physicians to define the consequences of chronic athletic training and competition to the participant. Coincident with the growth of public interest in sporting competition has been the evolution and development of new non-invasive technologies in cardiology (such as M-mode and two-dimensional echocardiography and radionuclide angiography) which have permitted investigators to study directly and more precisely the morphology and function of the heart and cardiovascular system. Hence, over the past several years our knowledge has been greatly enhanced with regard to the features of the normal 'athlete heart' and the relationship of athletic conditioning to preexistent cardiovascular disease, as well as the causes of sudden death in athletes.

The present treatise on 'Sports cardiology: Exercise in Health and Cardiovascular Disease' is an impressive reference document which is also timely. It fulfills an important role in summarizing most of the available data that has been accumulated over the last 10 years in a large number of athletes participating in a variety of different sports. Drs. I. Bekaert and R. Fagard have assembled 29 impressive contributions from more than 75 respected investigators from different parts of the world; these chapters constitute the essence of the International Conference on 'Sports cardiology' held in Knokke, Belgium in May 1985.

This is a comprehensive book with broad scope. It begins with two chapters which describe in detail the 'athlete heart', including its significance, morphologic and functional features, and historical perspective. These contributions are followed by chapters describing the electrocardiographic, echocardiographic, and radionuclide angiographic findings in athletes. Also included are several chapters concerned with the impact of exercise programs on athletes, including those with or those without underlying cardiovascular disease. The final two chapters are devoted to the very important issue of sudden death in athletes and describe those cardiovascular diseases known to be responsible for sudden catastrophes on the athletic field, in youthful and in older athletes.

Barry J. Maron, M.D.

Preface

In May 1985 the Belgian working group on sports cardiology organized an international symposium in Knokke. Several years had passed since the last larger meeting on the topic was held in Rome in 1978. The program in Knokke comprised lectures by invited speakers and oral and poster presentations selected from the response to the call for abstracts. Because more and more physicians and health counsellors are confronted with exercise-related problems, and the research in the field is rapidly expanding, it was felt useful to publish a book based on material from the symposium. However, contributions were selected and additional authors invited, so that the book would be more than the mere proceedings of the meeting and cover four important topics in the field of sports cardiology. A major first chapter is devoted to the structure and the function of the heart of athletes, some parts directed to familiarize the practising physician with athlete's heart, others meant for the researcher in the field. A brief second chapter relates the benefit of physical activity for the healthy subject and discusses aspects of the screening process. The third chapter covers exercise for the patient with cardiovascular disease, mainly coronary heart disease, Wolff-Parkinson-White pattern, hypertension and congenital heart disease. Finally the rare but dramatic event of exercise-related sudden death is reviewed.

Any book is open to criticisms and the editors are aware of some. The book is certainly not complete, but topics on which only personal opinions can be given, without hard data, were not included. Since the book has been written by several authors, some contradictions in facts and opinions do occur. The editors have not tried to reconcile divergent views and leave the role of referee to time and future research.

We express our gratitude to all authors and welcome any criticism or suggestions which may be helpful in a future edition.

R.H. Fagard
I.E. Bekaert

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CHAPTER I

ATHLETE'S HEART

The athlete's heart: an overview

I. BEKAERT

The majority of the cardiovascular changes or abnormalities that occur during vigorous sports activity in response to severe strain should be considered physiological adaptations. However, it is not always easy to distinguish between the physiological and pathological characteristics of certain abnormalities. The effects of sports activities or exercise training on the heart depend not only upon the frequency, but also the type of sports activity [1, 4, 13].

In general, two main types of sports can be distinguished – 'endurance' sports and 'strength' sports. 'Endurance' sports, e.g., road cycling and long-distance running, evolve an aerobic metabolism; oxygen transport mechanisms are stimulated in this kind of sport, and cardiac output is substantially increased [27]. The heart is subjected to a volume load, causing eccentric hypertrophy and an increase in end-diastolic volume [1, 4, 13]. The typical 'strength' sports, such as wrestling, shot-putting, etc., are anaerobic and demand great physical strength. They are characterized by an increase in the arterial blood pressure and mainly a pressure load on the heart, producing concentric hypertrophy and thickening of the ventricular walls without an increase in end-diastolic volume [1, 13].

In recent studies, however, there has been a lot of controversy over these two forms of adaptation, since increased wall thickness may also be observed in top-class athletes (albeit at a later stage) who engage primarily in 'endurance' sports.

End-diastolic volume, maximal stroke volume and maximal cardiac output are closely correlated. The maximum oxygen transport capacity of the cardiovascular system is determined by the maximal cardiac output. Cardiac adaptation can therefore contribute to the high oxygen uptake values found in athletes who participate in endurance sports [1]. Maximum oxygen uptake is further determined by peripheral oxygen extraction capacity; significant adaptations may also occur at this level during endurance training [1]. Moreover, physical performance or maximum oxygen uptake is mainly genetically determined, and can be increased only by about 20 to 30% by training [1].

Endurance training is associated with increased vagal tone and decreased sympathetic tone; this explains why both resting heart rate and heart rate during submaximal exercise are low in well-conditioned endurance athletes. This training bradycardia has as its corollary more efficient heart function, since myocardial oxygen uptake is determined primarily by the heart rate [1, 4, 13].

Cardiologists are confronted daily with patients asking whether they may continue to practise their favourite sports or elderly patients who still wish to engage in sports. The abnormalities which the cardiologist may observe during physical examination or on the resting – or exercise – ECG may be pre-existing phenomena and, hence, unrelated to physical conditioning. But they may also result from intense physical activity, in which case they should be considered normal variants. A differential diagnosis revealing possible underlying cardiac disease is therefore often difficult to make in such cases.

The most frequent alterations that should be considered normal include:

a) *upon physical examination:* the occurrence of systolic murmurs in the third left intercostal space and a third and/or fourth heart sound [32]. The anthropomorphic examination reveals a low body fat content.

b) *on the ECG* (Figure 1) one may find frequent sinus bradycardia, mainly resulting from increased vagal and decreased sympathetic tone in response to endurance work. Furthermore, signs of left ventricular hypertrophy and/or associated right ventricular hypertrophy may be observed [23, 35, 39, 40]. Other normal variants are: *conduction disturbances*, such as signs of incomplete right bundle branch block, as well as first-degree atrioventricular block, second-degree AV block and even third-degree AV block, the latter being rather rare (these atrioventricular conduction disturbances usually disappear during exercise or on specific autonomous reflexes or pharmacological tests [8, 19, 29, 44]; *repolarization abnormalities*, which may take the form of typical signs of increased vagal tone with ST segment elevation and enlarged T waves, especially in the precordial leads. Unusual patterns are occasionally observed during repolarization. Besides enlarged T waves, flat biphasic or negative T waves may also be seen, usually disappearing during exercise. Most of these are not pathological, but rather indicate good training conditioning. However, they may also reflect a pathological condition or pericarditis [11, 45]. Rhythm disturbances such as sinus bradyarrhythmias as well as sinus arrests of less than two seconds may occur. Extreme bradycardias of less than 40 beats/min may occasionally occur, even with episodes of junctional or ventricular escape rhythm. Ventricular extrasystolae may also appear on the resting ECG; they will usually disappear during exercise [29, 40]. If these ventricular extrasystolae persist or increase during exercise they should be considered potentially pathological and further examination will be required to exclude the possibility of underlying cardiac disease, e.g., cardiomyopathy, mitral valve prolapse or coronary heart disease [29, 40, 42].

c) *on exercise stress testing:* the physical work capacity is usually evaluated by a bicycle ergometer or treadmill exercise test. The maximal oxygen consumption level is one of the main indices for evaluating endurance capacity level. Measurement of the respiratory parameters, however, requires a maximal exercise test

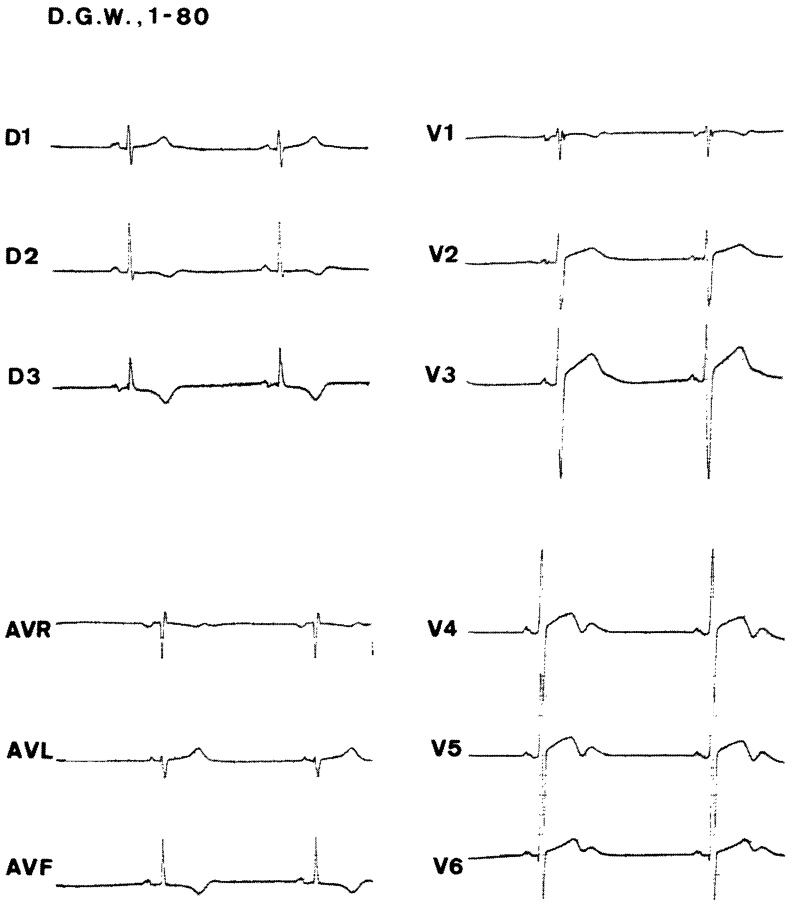

Figure 1. A typical electrocardiogram of a professional cyclist with sinus bradycardia, incomplete right bundle branch block, J point and ST segment elevation and biphasic T waves.

and a wide range of sophisticated equipment [1]. It is usually not possible for a general practitioner of sports medicine to determine oxygen consumption levels. He will therefor determine the physical work capacity (PWC) by recording heart rate. The usual parameter for PWC evaluation is PWC 170 (Physical Work Capacity 170), corresponding to the work load necessary to increase heart rate to 170 beats/min during a standardized bicycle ergometer exercise test [1]. The highest maximum oxygen intake and PWC 170 values are found in well-trained

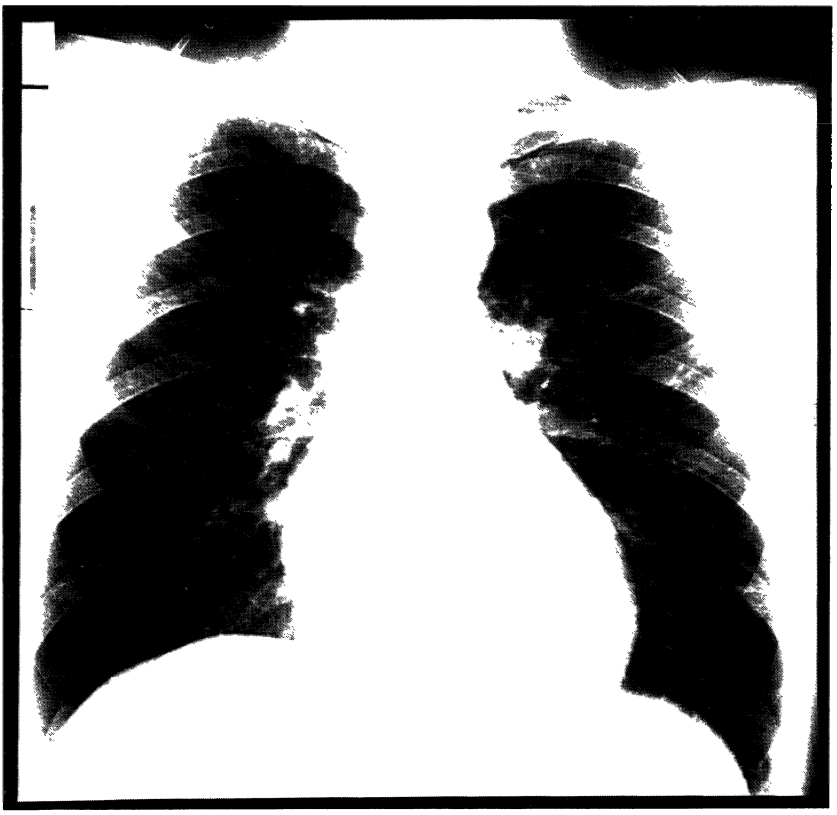

Figure 2. An X-ray examination of a professional cyclist with global enlargement of the heart and a prominent pulmonary arch.

endurance athletes (professional cyclists, cross-country skiers, distance runners), whereas in athletes engaged in strength sports they do not differ very much from the values found in active healthy control subjects [4].

d) *on radiologic examination* (Figure 2): Frontal and lateral chest X-rays provide an overall view of heart size and configuration. Globularly increased cardiac size is frequently observed in athletes, especially in those engaged in endurance sports. The cardiothoracic ratio is usually 0.50 or greater. These findings used to give rise to a lot of controversy, and physicians have more than once advised athletes to stop their athletic careers because they presented a significantly increased cardiac silhouette. However, enlarged hearts in athletes have now become commonly recognized and are considered a physiological adaptation.

Total heart volume may be calculated from the chest roentgenogram by the

method of Musshof and Reindell [31]. Mean heart volume is 700 to 800 ml in a sedentary population and 1,100 ml in endurance-trained athletes [15]. Top-class athletes (professional cyclists, cross-country skiers, etc.) frequently have heart volumes of 1,400 ml, and exceptional cases of volumes of 1,800 ml have even been described.

e) *on echocardiographic examination:* Echocardiography is one of the major techniques for cardiac examination. The echocardiogram allows visualization of the internal cardiac structure and specific study of left ventricular function. The diameters of the left ventricle and wall thickness can be measured during precise phases of the cardiac cycle, and the corresponding volumes and ventricular mass can be estimated from these dimensions.

The use of echocardiography has entirely changed and expanded our insights into the athlete's heart, and has suggested that the heart responds differently to different types of sports. Endurance athletes, such as runners, were thought to develop ventricular dilatation or increased LV diameter rather than hypertrophy or increased ventricular wall thickness, whereas athletes engaged in sports with a large isometric component, e.g., wrestlers and shot-putters, were said to develop hypertrophy but not dilatation [22, 32, 33, 43]. However, the controversy over these two forms of adaptation is still great since increased wall thickness may also be seen (albeit at a later stage) in top-class athletes who devote themselves to 'endurance' sports [3, 5–7, 24, 28]. This suggests that the pattern of LV hypertrophy in athletes is not as specific as was previously thought (Figure 3).

A lot of investigations look at correlations between heart size and PWC. Studies in healthy subjects show good correlation between total heart volume measured with a radiological method and the different parameters of maximal aerobic performance level [1]. We also found good correlations among maximal oxygen consumption, the peak oxygen pulse, and the echocardiographically measured left ventricular dimensions, as illustrated in Figure 4 [3, 26].

Such correlations are very important in distinguishing between physiological and pathological cardiac enlargement, since pathological enlargement, unlike physiological, healthy cardiac hypertrophy, is not accompanied by a corresponding increase in maximal oxygen uptake, and consequently may even lead to sudden death.

It is very important for the prevention of sudden cardiac death in athletes to have precise criteria for contraindicating athletic activity. The number of sudden deaths is greater than suggested by the statistics [2, 9, 12, 16–18, 20, 21, 24, 25, 34, 36–38]. The most frequent cause of sudden death in young, healthy subjects under 35 years of age is cardiomyopathy, especially hypertrophic cardiomyopathy, and asymmetric septal hypertrophy in particular [18–24]. In sportsmen over the age of 35 the most frequent cause is, of course, coronary heart disease.

Other known causes of sudden death may be myocarditis, unrecognized valvu-

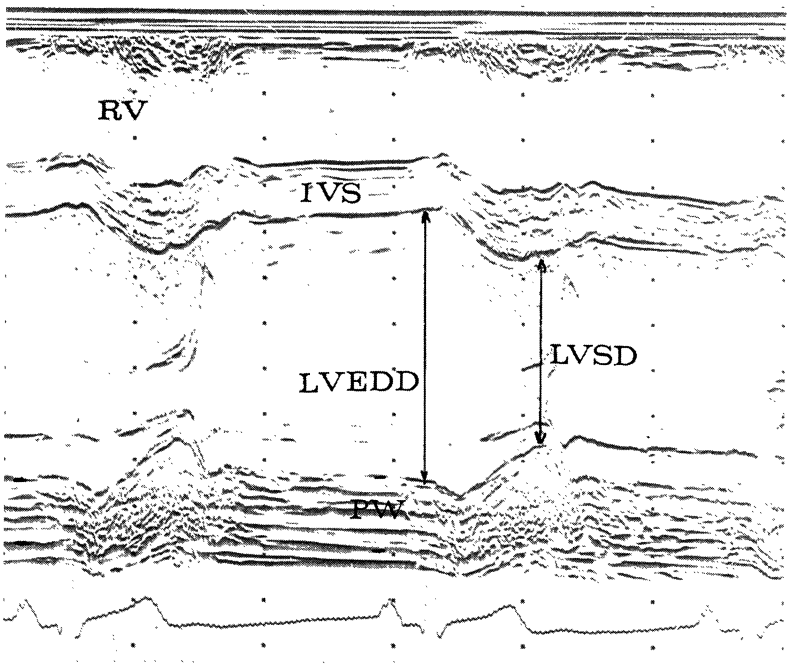

Figure 3. An echocardiogram of a profession cyclist with enlargement of the left ventricular diameters (end-diastolic and end-systolic) and increased thickness of the left ventricular walls.
Abbreviations: IVS: interventricular septum; LVEDD: left ventricular end-diastolic diameter; LVSD: left ventricular end-systolic diameter; PW: left ventricular posterior wall; RV: right ventricle.

lar heart disease, such as aortic valvular stenosis and mitral valve prolapse, congenital anomalies of the coronary arteries, etc. [2, 12, 16, 17, 20, 21, 25, 38, 41]. Regular sports activity improves the quality of life, although no significant effect is seen on morbidity and mortality in high-risk patients, such as those suffering from coronary heart disease. Nevertheless, vigorous exercise may have a negative effect and even lead to sudden death, especially in untrained individuals [36–38]. The long-term effects of sports activities are still the subject of continual, heated debate.

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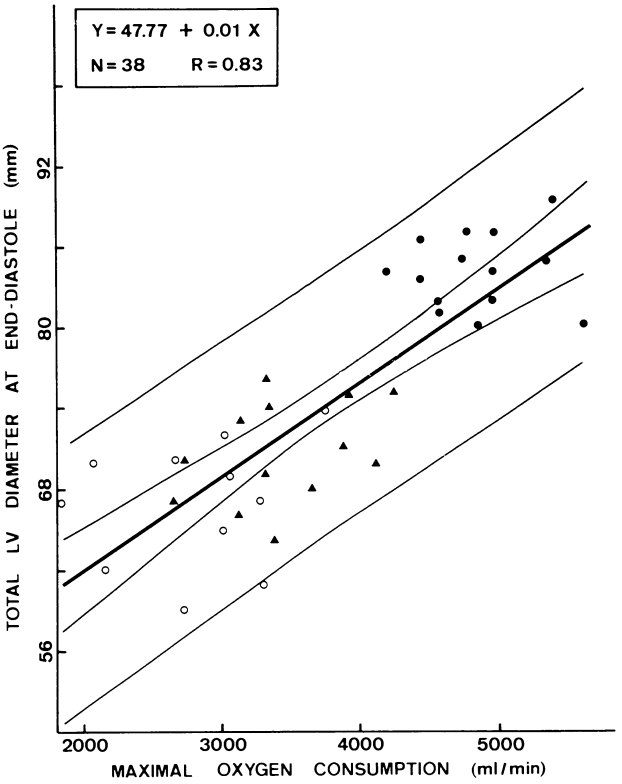

Figure 4. Relationship between total left ventricular diameter on echocardiography and maximal oxygen consumption. The lines indicate the regression equation, the 95% confidence limit of the regression and the 95% confidence limit of the observations. The symbols identify medical students (○), active middle-aged subjects (▲) and professional cyclists (●).

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12

Athlete's heart: a 100-year long discussion

R. Rost

Summary

For nearly 100 years there has been a debate concerning the significance of the athlete's heart (AH), whether this is a case of physiological hypertrophy or a pathological phenomenon. We here summarize some of the most important data from the clinical, epidemiological and anatomical literature, clearly demonstrating that AH must be considered to be a physiological phenomenon. Nevertheless, in view of the increasing intensity of training and the participation of new age groups such as prepubescent children and the elderly in top-level endurance sports, a fresh discussion of these old questions is required. Furthermore, any answers will be modified by the use of new diagnostic methods. In our own studies, we have found that the limits of physiological cardiac hypertrophy are not exceeded. On the other hand, the possibility that training may accentuate pre-existing subclinical damage cannot be excluded. This may be the case in the elderly or in the presence of a genetic predisposition to pathological hypertrophy such as hypertrophic cardiomyopathy. We discuss some of the interesting questions pertaining to this subject, whether historically unanswered or arising from the application of new diagnostic techniques in modern top-athletics.

Introduction

A number of factors have recently led to a renewal of the discussion of athlete's heart (AH) assessment, in particular the introduction of non-invasive techniques such as echocardiography, Holter monitoring, computerized axial tomography, myocardial scintigraphy, etc. These methods are particularly well-suited for examination of healthy athletes in whom invasive techniques are clearly inappropriate. A second reason for the increased interest in the effects of cardiac training originates in the expected beneficial effects of physical exercise in cardiac patients, particularly on the basis of our experience with the athletic population. A third reason could be found in the increasing intensity of training and the participation of new age groups such as prepubescent children and the elderly in top-level competition sports, allowing new possibilities for physiological adaptation, as well as introducing new risks.

Discussion of AH has been underway for some 100 years, a fact which often appears to be forgotten in the modern literature on this topic. AH was first described by Henschen [4] at the end of the last century, and the answer to some of the questions considered unsolved by some modern authors are to be found in the published documentation of nearly one century of research on this subject. A short historical review of the evolution of this discussion would therefore seem useful.

The major question is whether AH can be considered to be a physiological or a pathological entity. After nearly one hundred years of research, we can confirm the statement by Henschen that 'an enlarged heart is something good if it is able to perform an enlarged work over a long period'. Nevertheless, this opinion has been subject to continuous debate. The idea that AH constitutes a cardiac illness can be readily understood in view of the size, physiological properties and clinical abnormalities encountered. The physiologist observes cardiac enlargement in animal models of heart failure and regards this as a sign of overload, while the physician is confronted with cardiac enlargement primarily in the case of congestive heart disease where this enlargement is generally an important diagnostic factor. Furthermore, improved diagnostic facilities do not necessarily improve the quality of assessment. Henschen's ingenious interpretation was based on findings by percussion; he used only his fingers and his brain. Later investigators came to false interpretations in spite of sophisticated technical measures, as illustrated by the subsequent examples.

Moritz was the first to use X-ray studies in his investigation of AH [10]. He refused to accept the classification of AH as a purely physiological entity, and sought to fit it into his model of cardiac enlargement by acute overload (tonogen dilation) and cardiac failure (myogen dilation). Along with Dietlen [2], he feared that 'continuous and heavy work in sports might result in more rapid wear on the cardiovascular system'.

The widespread belief that professional athletes do not live long has been based on this notion. According to a survey by Roskamm *et al.* [12] this opinion was widespread in the 19th century English literature. Nevertheless, results of epidemiological studies summarized by these authors do not support such a hypothesis. The most striking misinterpretation is found in the standard textbook of cardiology, edited by Friedberg, in which AH is considered to be, among other things, the consequence of syphilitic heart disease. These older notions concerning AH have been replaced by more modern arguments in the literature, and Keren [6] concluded that 'Sudden death . . . appears to be more frequent among sportsmen. This seems to be due to the changes which constitute the so-called AH'; there is no proof of this assertion.

All of these misgivings about AH are summarized in the American literature under the term of 'athlete's heart syndrome'. According to the author's medical dictionary, a syndrome means a 'group of signs of a disease which appear simultaneously'.

Literature results

At present, it would seem useful to discuss some of the major findings of previous studies. It would of course be interesting to have available anatomical data on apparently healthy athletes, and there are several pathological-anatomical studies of sudden death during sports activities where underlying disease can be demonstrated. Nevertheless, these cannot be considered to be representative of a healthy athletic population, since there is a striking lack of data on athletes who died of causes unrelated to the cardiovascular system. Today, we still depend upon the anatomical data of Kirch [7], even if these data are unsatisfactory in view of the enormous difference between the intensity of training of top-ranked athletes in his time and at present. Nevertheless, some of these conclusions are still valid.

Made public in two lectures in 1935 and 1936, Kirch's findings concerned 35 athletes who died suddenly during or independently of physical activity, most of them in accidents. Kirch pointed out that physical training clearly resulted in cardiac hypertrophy, while some pathologists previously considered cardiac enlargement to simply constitute part of an overall muscular training, Kirch found that there was a doubling in heart size by comparison with the normal range. He considered that these hearts were healthy, and that hypertrophy could spontaneously resolve after the cessation of training.

There is a second important conclusion which can be drawn from these findings, e.g. the preponderance of right ventricular hypertrophy unrelated to the specific type of sport. For this reason, the term 'harmonious hypertrophy' introduced by Linzbach [8] cannot be defined as a symmetric enlargement of all chambers as has frequently been the case. This term implies an exact correspondence between the physiologically hypertrophied cardiac muscle and the normal heart. On the contrary, according to Linzbach a pathological hypertrophy results from a 'structural dilation' (= Gefügedilatation), the precondition of heart failure. This structural modification will occur if the 'critical heart weight' of 500 g is exceeded, which is never the case in AH.

From these findings, we can conclude that physiological hypertrophy always remains within reasonable limits. While unlike some other authors, Linzbach did not exclude the possibility of myocardial hyperplasia, he did stress the fact that it was never found in physiological hypertrophy; in the pathological entity, there may be a loss of this physiological limitation with a risk of deterioration in the myocardial blood supply due to unrestricted hypertrophy. The current development of athletic activity seems to substantiate the existence of this physiological limit to cardiac enlargement; despite increased training, radiological studies show that the hearts of athletes are currently no larger than those observed by Reindell *et al.* [11] in the 1950s. Therefore, the limits of cardiac adaptation during training appear to be rapidly attained, and further improvements in performance are probably due primarily to metabolic and peripheral vascular adaptations.

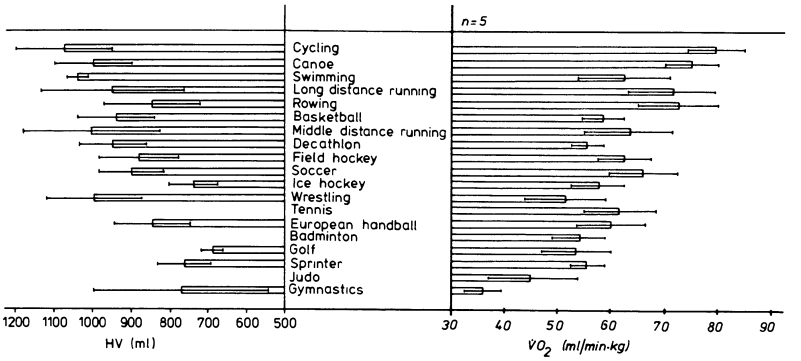

Figure 1. Cardiac volume (HV: left side) and maximal oxygen uptake (VO_2: right side) in top athletes.

Clinical studies of AH were previously based particularly upon radiological studies. For quantitative assessment of AH, Reindell introduced into sports medicine the radiological measurement of cardiac volume first described by the Scandinavian authors. His studies showed both absolute and relative (weight-related) cardiac enlargement, particularly in endurance athletes whose hearts were up to twice the size of those of untrained subjects. To differentiate between these physiologically large hearts and the diseased, Reindell compared the size of the heart with its functional capacity, combining radiological studies with spiro-ergometric measurement of maximal oxygen uptake (introduced into sports medicine by Hollmann [5]). Reindell postulated that the heart can be considered to be healthy only when it is able to transport a quantity of oxygen corresponding to its enlargement, confirming the remarks by Henschen (Figure 1).

Electrocardiography (ECG) has not proved to be a useful tool in the non-invasive assessment of myocardial hypertrophy. There is wide agreement in the literature that electrocardiographic indices of hypertrophy are poorly correlated with anatomical findings. Our own results on this subject are presented in the paper by Reinke, in this volume. Nevertheless, ECG clearly shows the effects of increased vagal tone in AH with bradycardia, substitutional rhythms, atrio-ventricular (AV) conduction abnormalities, etc. The range considered to be 'normal' on the ECG has been considerably widened by the introduction of Holter monitoring. Phenomena such as Mobitz type II AV block or third-degree functional AV block, previously considered to be entirely pathological, are now regularly reported in healthy athletes. Repetitive premature beats may also occur in athletes, however these may be present in untrained subjects as well. According to our experience, there is no higher incidence of such arrhythmias in athletes, and therefore, no increased risk of sudden death, as concluded by Keren [6].

The introduction of echocardiography has given a new impetus to the discussion of AH, and athletes constitute particularly good subjects for this technique.

Sports medicine depends solely on non-invasive methods, and since our first presentation of echocardiographic results for athletes participating in the Munich Olympic Games [15], a large number of new studies have been published.

Concerning the morphological aspects of AH, Morganroth *et al.* [9] recently suggested that some form of cardiac adaptation may also occur in strength athletes in whom he found a 'pure concentric hypertrophy' in contrast to the 'pure dilation' seen in endurance athletes. Nevertheless, at least in its absolute form this cannot be accepted from the theoretical standpoint; due to the increased myocardial wall strain predicted from Laplace's law, dilation must be accompanied by hypertrophy, even in endurance athletes; this would result in eccentric hypertrophy.

Published opinions concerning the effects of isometric training on cardiac hypertrophy are not unanimous. Our own results did not confirm a predominantly concentric hypertrophy after strength training. A recent study by Dickhuth [1] using two-dimensional echocardiography yielded similar conclusions. One possible source of error may be incorporation of papillary muscles into the septal echo. While, of course, concentric hypertrophy can be found in athletes, it is not restricted to strength athletes. Generally speaking, highly controversial changes such as the preponderance of concentric hypertrophy after isometric training are not of major significance.

Questions open to discussion

In summary, we may conclude that AH is a product of physiological hypertrophy and can be considered to be a normal adaptive phenomenon. What questions remain open for discussion? Three of the most relevant will be discussed below:

1) Is there a genetic predisposition that favours the development of AH, and if so, what form does it take? Do the large hearts of top-level athletes constitute genetic exceptions, or can all hearts reach the same size in training?

This question is of major importance, and if congenital factors are involved, then future Olympic champions could be selected on the basis of large heart size, while children with hearts of only normal size could be discouraged from becoming involved in top-level endurance sports.

The possibility of a purely congenital abnormality can be excluded since cardiac enlargement of this type has never been described in untrained healthy subjects. Conversely, even if training does play an important role, the exact importance of genetic factors, possibly decisive, remains open and can be answered only by long-term longitudinal and cross-sectional studies of athletic populations. This is not a realistic prospect since it would obviously be impossible to investigate all persons beginning to practise sports in order to obtain baseline data on later champions.

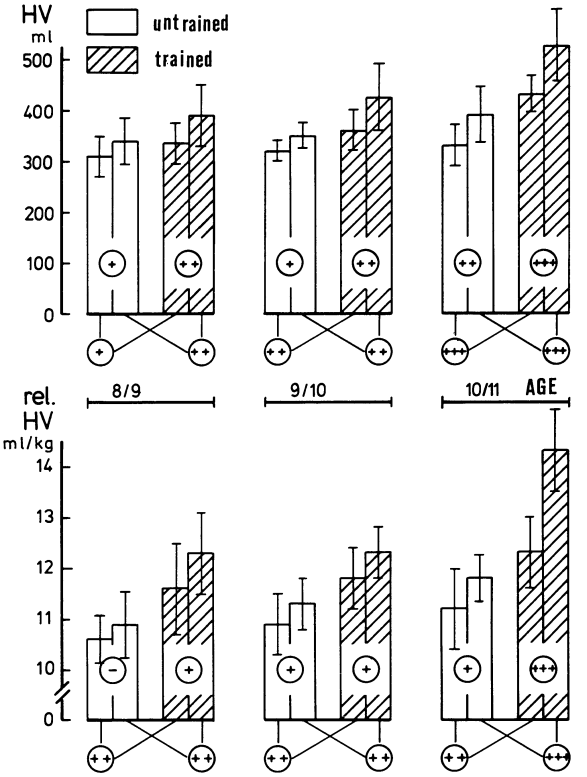

Figure 2. Results of a cross-sectional and longitudinal study in young competitive swimmers, compared to an age-matched group of untrained children. Each group comprised 6 girls and 6 boys, aged between 8 and 10 years. All children were re-examined one year after the first study. There was a significant increase in cardiac volume (HV) in the trained children, with the difference increasing after a further year of training. In this same study, we found the same difference with regard to performance capacity and echocardiographic evaluation of cardiac hypertrophy [14].

2) Should we expect previously unseen effects of training on the heart since new age groups, both young children and the elderly, are now engaged in endurance sports. While there are no data currently available to enable us to predict the effect of marathon running on the hearts of 70-year old persons, we do have some results available in children. Prepubescent children are currently involved in endurance sports, in particular in swimming, and this poses some interesting questions. Are the effects of training on the cardiovascular system already seen at this age? Can training at this age lead to a major increase in cardiac volume in view of the greater elasticity of children's hearts? Does an early beginning of training pose any particular cardiac risks?

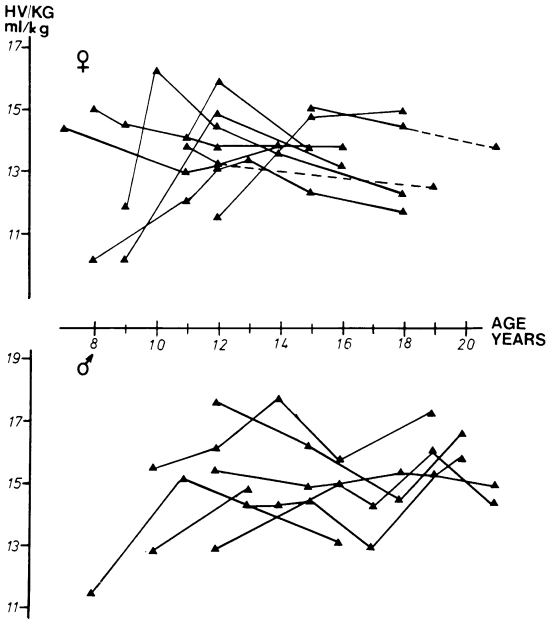

Figure 3. Changes in weight-related cardiac volume (HV/kg) in competitive swimmers, beginning training very early. Each line combines the individual values for one subject [14].

In order to answer these questions, we have carried out both longitudinal and cross-sectional studies in young swimmers over a period of 12 years. Some of these children later went on to win Olympic medals. Our findings have clearly demonstrated that in this age group, development of AH is already seen (Figure 2). Nevertheless, the limits of physiological hypertrophy are respected, and the hearts of these children reached their maximal weight-related size at puberty (Figure 3); cardiac size did not exceed that of swimmers beginning training at a later age. No evidence for development of cardiac damage due to intensive training was found over this long period of observation [14].

3) Even if AH does result from physiological hypertrophy, the question arises as to whether training may lead to clinical symptoms due to accentuation of minor damage or genetic predisposition which have remained subclinical. As noted above, elderly persons are now beginning to train more intensively, and increased vagal tone may cause problems in conjunction with a slight sick sinus syndrome or AV block. In such cases, endurance training could eventually necessitate implantation of a pacemaker, and we have observed some cases supporting this hypothesis. Another question is whether initially physiological hypertrophy could eventually lead to pathological hypertrophy in case of a genetic predisposition to

hypertrophic cardiomyopathy (HCM). It is sometimes rather difficult to distinguish between clinical signs of AH and HCM, since electrocardiographic changes in repolarization as well as echocardiographic patterns of hypertrophy may be similar in both types. This question is currently not answerable, and further research on this age-old debate will be required to answer these new suspicions.

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§1. ELECTROCARDIOGRAPHY IN ATHLETES

Rhythm and conduction abnormalities

R. CAMPBELL

Summary

Athletic training produces marked adaptations in the structure and function of the heart. The main electrocardiographic (ECG) manifestations of these changes are bradycardia (reflecting an increased stroke volume and high vagal tone), atrioventricular (AV) conduction disorders (reflecting high vagal tone) and ventricular hypertrophy. The frequency of ECG abnormalities may vary according to the type of athletic pursuit.

In one study, the minimum nocturnal heart rate range of athletes was 24–48 beats/min (33–63 beats/min controls). Sinus pauses (R-R >2.0 sec) have been observed in up to 37% of athletes (<6% in normal population). Up to 23% of athletes show resting Wenckebach AV block (<10% in normal population) with up to 9% showing a Mobitz type II pattern (<1% in normal population). Junctional escape rhythms are common as are ventricular ectopic beats but ventricular tachycardia and other serious arrhythmias are rare. ECG criteria for left ventricular hypertrophy (LVH) are of low sensitivity and specificity and include a high proportion of young normal subjects. Electrocardiographic evidence of LVH has been reported in up to 80% of athletes when voltage criteria are employed.

Although athletes show more 'physiological' rhythm and conduction disturbances than similar age-matched but less well-trained controls, pathological abnormalities are extremely rare.

Introduction

Cardiac rhythm and conduction abnormalities would seem unlikely findings in athletes. Yet not infrequently, ECG disturbances are present, some being identical to those considered pathological in other populations. Individuals who are physically trained can achieve a greater cardiac output for any given pulse rate than comparable, but unfit individuals. The increased stroke volume by which this is accomplished is the consequence of ventricular dilatation and hypertrophy. At rest, an appropriate cardiac output is maintained by a low heart rate in the setting of high vagal tone.

Table 1. Electrocardiographic features in studies of athletes.

Study	Population	Age	n	Tech	Heart rate		Sinus pauses	1st AVB	2nd AVB		CHB	AVD	VEBs	VT
					Mean	Range			Wencke-bach	Mobitz II				
Smith *et al* 1964 [18]	Marathon runners	–	21	ECG	56	38–78	–	–	–	–	–	–	–	–
Van Ganse *et al.* 1970 [21]	Athletes (cyclist)	$\overline{22}$	30	ECG	53	44–75	–	–	–	–	–	–	–	–
	Control	$\overline{22}$	30	ECG	71	53–98	–	–	–	–	–	–	–	–
Meytes *et al.* 1975 [13]	Athletes	–	126	ECG	–	–	–	–	9%	2%	–	–	–	–
Roeske *et al.* 1976 [15]	Athletes	21–31	42	ECG	–	–	–	–	2%	–	–	–	–	–
	Control	–	10	ECG	–	–	–	–	0%	–	–	–	–	–
Roskoff *et al.* 1976 [17]	Marathon runners	18–72 ($\overline{38}$)	30	ECG	52	38–66	–	–	–	–	–	–	–	–
Parker *et al.* 1978 [14]	Long distance runners	$\overline{26}$	12	ECG	50	39–58	–	–	–	–	–	–	–	–
	Normal control	$\overline{29}$	12	ECG	61	45–77	–	–	–	–	–	–	–	–
Ikaheimo *et al.* [8]	Athletes (sprinters)	$\overline{24}$	10	ECG	59	52–70	–	10%	–	–	–	–	–	–
	Athletes (endurance)	$\overline{29}$	12	ECG	55	40–100	–	8%	–	–	–	–	–	–
	Control	$\overline{25}$	13	ECG	74	56–96	–	0%	–	–	–	–	–	–

Table 1. Electrocardiographic features in studies of athletes (cont.).

Study	Population	Age	n	Tech	Heart rate		Sinus pauses	1st AVB	2nd AVB		CHB	AVD	VEBs	VT
					Mean	Range			Wencke-bach	Mobitz II				
Talan *et al.* [20]	Endurance runners	19–28 ($\overline{21}$)	20	DCG	73 awake 47 sleep	34–164 31–114	95% (>1.75 sec)	–	40%	–	–	–	70%	–
Viitasalo *et al.* 1982 [23]	Athletes	–	35	DCG	38 sleep/min 124 awake/max	24–164	37% (>2 sec)	37%	23%	9%	–	20%	–	0%
	Control	$\overline{23}$	35	DCG	45 sleep/min 137 awake/max	33–168	6% (>2 sec)	14%	6%	0%	–	0%	–	6%

Abbreviations: DCG = Dynamic electrocardiogram (24-h Holter recording); TECH = Technique; AVB = Atrioventricular Block; CHB = Complete heart block; VEBs = Ventricular ectopic beats; VT = Ventricular tachycardia; AVD = Atrioventricular dissociation; LVH = Left ventricular hypertrophy; RBBB = Right bundle branch block.

ECG features of LVH (with attendant delay in transventricular conduction), sinus bradycardia, sinus arrhythmia, sinus pauses, first- and second-degree AV block, and junctional escape rhythms might all be expected to be common in athletes and should perhaps be considered 'physiological'.

Investigation of the incidence of ECG abnormalities in athletes is seriously hampered by the paucity of published evidence, by the highly selected nature of those investigated, by the variability of definitions and techniques and by the difficulty of selecting appropriate 'control' or comparison populations.

Heart rate

Several comparative studies have confirmed that the resting heart rate of trained athletes is significantly lower than that of age-, sex- and weight-matched controls (Table 1) [8, 14, 15, 21, 23]. Peak heart rates in athletes and controls are similar [8, 23] but the augmented stroke volume of athletes means that the latter can achieve a much greater cardiac output.

Sinus pauses

There is no generally agreed normal value for sinus pauses and in published studies different definitions have been used. Talan *et al.* [20] found sinus pauses in 95% of 20 athletes investigated, but their definition of greater than 1.75 sec is not particularly demanding (equivalent to a heart rate of 34 beats/min). Viitasalo *et al.* [23] using a more stringent definition of greater than 2 sec found sinus pauses in 37% of athletes and in only 6% of normal controls.

First-degree AV block

First-degree AV block has been noted in about 40% of athletes [20, 23] and in 0.65–14% of normal 'controls' [2, 3, 5, 7, 23]. The wide variation in the latter values is probably attributable both to variations in the technique for ECG recording (the standard ECG or dynamic electrocardiography) and to the level of fitness in the chosen subjects. An 8% incidence of first-degree heart block was found by Brodsky *et al.* [2] in fit medical students and a 14% incidence by Viitasalo *et al.* [23] in fit medical students and Army conscripts.

Second-degree AV block

Viitasalo *et al.* [23] found a high frequency of both Wenckebach and Mobitz type

II AV block in athletes when compared with controls (23% vs. 6% and 9% vs. 0% respectively). Other workers have found Wenckebach block in 2–9% [13, 15] and Mobitz block in 2% [13] of athletes. Corresponding figures for normal populations range from 0–6% for Wenckebach block [2, 3, 5, 7, 23] and 1% for Mobitz block [3].

Complete heart block and AV dissociation

Complete heart block has not been detected in any study of athletes or normal control populations (Tables 1 and 2). Viitasalo *et al.* [23] observed a 21% incidence of AV dissociation in athletes and 0% in controls. Clarke *et al.* [3] described a junctional escape rhythm in 9% of dynamic electrocardiogram recordings (DCG; 24 hour Holter) from a normal population.

Ventricular arrhythmias

The proportion of athletes with ventricular ectopic beats on 24-h DCG tapes has been described as 20% [20] and 70% [23]. The figures for comparable normal populations range from 0%–73% [1, 2, 3, 9, 10, 22, 23]. Ventricular tachycardia has not been seen in athletes DCG recordings, but has occurred in 0–6% of normal subjects [1, 2, 3, 9, 10, 22, 23].

Left ventricular hypertrophy

In over 70% of trained athletes, voltage criteria for left ventricular hypertrophy (SV1 plus RV5 or RV6 >35 mV) are satisfied [17, 18, 24]. Using the Romhilt and Estes point scoring system [16], left ventricular hypertrophy will be diagnosed in approximately one third of athletes and rarely in normal control populations [14, 15, 17] (Table 3).

Right bundle branch block

The reported incidence of right bundle branch block (partial or complete) has varied widely in published series. This feature was not seen by Parker *et al.* [14] in their study of 12 long-distance runners. By contrast, Ikaheimo *et al.* [8] reported a 70% incidence in sprinters and 33% incidence in endurance runners. In this latter study, right bundle branch block was not seen in any of the 13 control subjects contrasting with the report of Van Ganse *et al.* [21] who found a 20% incidence of the phenomenon in their control population.

Table 2. Electrocardiographic features in studies of non-athletic but normal populations.

Study	Population	Age	n	Tech	Heart rate		Sinus pauses	1st AVB	2nd AVB		CHB	AVD	VEBs	VT
					Mean	Range			Wencke-bach	Mobitz II				
Graybiel *et al.* 1944 [5]	Aircrew		1000	ECG	–	–	–	1.1%	0%	–	–	–	–	–
Hiss/Lamb 1962 [7]	Asymptomatic Aircrew		122043	ECG	–	–	–	0.65%	0.003%	–	–	–	–	–
Clarke *et al.* 1976 [3]	Normal population	16–65	86	DCG	–	–	–	1%	2%	1%	0%	9%	73%	2%
Brodsky *et al.* 1977 [2]	Normal male students	23–27	50	DCG	–	–	4% (>2 sec)	8%	6%	–	–	–	50%	2%
Viitasalo *et al.* 1979 [22]	Active normals	$\overline{49}$	15	ECG / DCG	164 peak	–	–	–	–	–	–	–	47%	0%
	Sedentary normals	$\overline{48}$ –	15	ETT	164 peak	–	–	–	–	–	–	–	73%	0%
Barrett *et al.* 1981 [1]	Normal aircrew		–	DCG	–	–	–	–	–	–	–	–	0.7%	0.003%
Kostis *et al.* 1981 [9], 1982 [10]	Normal population	$\overline{49}$	101	DCG	99 max / 71 min	35–180	–	–	–	–	–	–	39%	0%
Sobotka *et al.* [19]	Normal female population	22–28	50	DCG	–	–	0%	–	–	–	–	–	–	–

Abbreviations: see Table 1.

Table 3. Incidence of LVH and RBBB in athletes and comparable normal controls.

Study	Population	Age	n	LVH voltage	LVH Romhilt/ Estes [20]	Partial/Complete Right bundle branch block
Smith *et al.* 1964 [18]	Marathon runners	–	21	76%	–	24%
Roskoff *et al.* 1976 [17]	Marathon runners	18–72				
		$\overline{38}$	30	80%	0%	–
Roeske *et al.* 1976 [15]	Athletes	21–31	42	80%	25%	43%
	Normal controls	–	10	–	–	–
Parker *et al.* 1978 [14]	Long distance runners	$\overline{26}$	12	–	33%	0%
	Normal controls	$\overline{26}$	12	–	0%	–
Ikaheimo *et al.* 1979 [8]	Athletes sprinters	$\overline{24}$	10	–	58%	70%
	Athletes endurance	$\overline{29}$	12	–	30%	33%
	Normal controls	$\overline{29}$	13	–	0%	0%
Zeppilli *et al.* [24]	Athletes (selected with					
	ST/T changes)	$\overline{26}$	8	75%	–	–
Van Ganse *et al.* [21]	Athletes (cyclists)	$\overline{22}$	30	–	–	27%
	Normal controls	$\overline{22}$	30	–	–	20%

Abbreviations: see Table 1.

Sudden death

Sudden death is rare in athletes, but its occurrence attracts substantial attention. There is no evidence to suggest, that the 'athletic heart' is more prone to develop life-threatening arrhythmias than the untrained heart. Indeed the converse may be true. In most published evidence, death in athletes can be attributed to the presence of overt or occult underlying cardiac disease [4, 11]. Maron *et al.* [11] found cardiovascular abnormalities in 97% of their investigated incidents.

Can vagotonia be pathological?

Resting high vagal tone is a feature of well-trained athletes. Its ECG manifestations may resemble some pathological situations. However, in athletes, symptoms are rare and sinus node and AV node function is normal on exercise. Notwithstanding, occasional situations have been reported when vagotonia has appeared responsible for symptomatic arrhythmic events [6, 12] and permanent pacing has been necessary. These circumstances are extremely rare.

Conclusion

The majority of ECG 'abnormalities' seen in athletes are physiological and carry no prognostic significance. Peak heart rates in athletes are similar to those of less fit controls, but the latter do not achieve comparable cardiac outputs. Ventricular ectopic beat activity is seen not uncommonly in normal populations and in athletes and is usually of very low frequency. Serious ventricular arrhythmias are rare in athletes. Electrocardiographic features of left ventricular hypertrophy are common in those who are athletically trained, but are also normal in young populations, the incidence varying widely according to the diagnostic criteria used. Right bundle branch block of either partial or complete forms appears frequently in athletes and to a lesser extent in normal populations. Sudden death does occur in athletes, but is rare and there is almost always evidence of underlying cardiovascular abnormalities.

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Bradycardia, ventricular pauses and sports

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Summary

Thirty-seven top-ranking athletes underwent 24-h Holter monitoring. Pauses longer than 2 sec occurred in 19% and resulted from sinus arrest. The longest pause lasted 2.5 sec. Second-degree atrioventricular block was noted in 13%.

Introduction

There is a need for establishing normal limits for a mean 24-h heart rate, minimal heart rate trends and pauses in highly trained athletes. Occasional case reports may create confusion in the evaluation of rhythm abnormalities in the individual athlete. We have studied a first group of 25 athletes in November 1981 (group A) and a second group of 12 long-distance runners in December 1982 – January 1983 (group B).

Some of the results here discussed have been partially reported elsewhere [5].

Methods

Twenty-five male athletes were investigated in November 1981 (group A). Age ranged between 17 and 34 years, and there were 21 long-distance runners, one 400-meter runner and 3 cyclists. Six belonged to the top international class, 7 to the top Belgian class and 12 others were well-trained athletes who won regional competitions. All athletes had been following an intensive training schedule for at least 4 years.

All subjects underwent 24-h Holter monitoring. They had electrodes and monitors attached to them in the dressing room of their respective clubs. Most had previously refused to have the recorder mounted in the hospital. History taking and physical examination were performed by a cardiologist. An additional survey of their athletic activities and performance was made.

Twelve other male long-distance runners (ages between 19 and 40 years) underwent 24-h Holter monitoring in December 1982 and January 1983 (group B). Two athletes were in the top international class, six in the top Belgian class

and four were well-trained runners. Besides medical history and physical examination, this group agreed to have a 12-lead ECG, exercise testing and an M-mode echocardiogram. A detailed survey of athletic performance activities was made.

Holter technique

All 24-h Holter recordings were made with two independent bipolar leads. We used a semi-automatic Oxford Medilog analyzer. The recording and analysis system incorporate a synclock mechanism, which, by providing and processing a reference time signal, ensured that variations in tape speed did not produce artefacts of rhythm or rate.

The Oxford Medilog analyzer yields a visual display of the heart rhythm on a 40-sec memory oscilloscope. Abnormalities are printed out on paper. Slowest heart rates were determined for noctural and diurnal periods and were calculated between 3 consecutive heart beats on a print-out. Strips containing abrupt pauses, were not considered for calculation of this frequency. Pauses were calculated in seconds.

The following features were required to meet criteria for ventricular pauses: (i) an RR interval of 2 sec or more; (ii) an abrupt change in RR interval. Regular RR intervals of 2 sec and more during a slow stable heart rhythm were not classified as pauses, i.e. in individuals with heart rates of 30/min or less.

Results

Results of Holter monitoring are presented in Table 1 (group A) and in Table 2 (group B). Summing data for both groups we have a total of 37 athletes.

Group B underwent an extensive non-invasive cardiologic investigation. Group A had been very reluctant to undergo investigational procedures. A simple medical history and clinical examination, with special attention to coronary heart disease risk factors, was performed and would have been sufficient to detect cardiovascular disease [9]. In none of the 37 athletes was there any evidence of structural heart disease.

Diurnal sinus bradycardia (<50/min) was present in 24/37 (64.9%) athletes, with nocturnal bradycardia in 33/37 (89.2%). Heart rates below 40/min occurred by day in 10/37 (27%) subjects and at night in 25/37 (67.6%). Heart rates below 30/min were seen only at night in 4/37 individuals (10.8%).

We found pauses of 2 sec in 19 athletes (51%) and pauses longer than 2 sec in 7 (19%). All pauses longer than 2 sec resulted from sinus arrest. The longest pause lasted 2.5 sec.

First-degree atrioventricular block (AVB) was noted in 6 athletes (16%) and second-degree AVB in 5 (13%). Athlete 2A (athlete No. 2 of group A) had 18

Table 1. Results of Holter monitoring in 25 male athletes: group A.

Athlete no.	Age	Slowest heart rate		SVPC (1)	VPC (2)	Pauses of 2 seconds		Pauses >2 sec (3)	AV block	
		Day	Night			Number/24 h	Etiology (3)		1st	2nd (4)
1	21°	35	32	–	4	10	S	–	–	–
2	29°	60	55	1	1	7	AV	–	PR 0.34	18 M1
3	29°	60	32	7	1	1	S	–	–	–
4	30°	44	37	235	–	–	–	–	–	–
5	26°	50	35	6	–	1	AV	–	–	10 M1
6	22°	40	42	1	–	–	–	–	–	–
7	24°	45	32	8	–	15	S	1/2.4/S (5)	–	–
8	22°	44	32	12	–	1	S	–	–	–
9	19°	45	34	1	–	–	–	–	–	–
10	24°	50	28	–	–	5	S	1/2.3/S (5)	–	–
11	25°	50	32	–	–	14	13 S + 1 AV	1/2.2/S (5)	–	1 M2
12	21°	50	41	–	11	3	S	–	–	–
13	21°	50	37	–	–	–	–	–	–	–
14	19°	43	45	–	–	–	–	–	–	–
15	20°	40	45	–	–	–	–	–	–	–
16	17°	50	32	4	–	–	–	–	–	–
17	23°	39	32	–	–	–	–	–	–	–
18	21*	50	60	–	–	–	–	–	–	–
19	18°	37	40	1	–	–	–	–	–	–
20	34°	41	45	–	–	–	–	–	–	–
21	19°	45	36	–	–	1	S	1/2.5/S (5)	–	–
22	27°	60	33	–	–	–	–	–	–	–
23	18+	47	34	–	–	–	–	–	–	–
24	21+	60	50	1	–	6	AV	–	–	6 M1
25	22+	45	40	–	–	2	S	–	–	–
Number of athletes with abnormality				11	4	12		4	1	4

° Long-distance runner
* 400 m runner
+ Cyclist

(1) SPVC: supraventricular premature contractions, number/24 hours
(2) VPC: ventricular premature contractions, number/24 hours
(3) S: pauses caused by sinus arrest or sino-atrial block; AV: pauses caused by AV block
(4) Number of episodes of Möbitz I (M1) and Möbitz II (M2) AV block, number/24 hours
(5) first number = number of pauses >2 seconds; second number = length of longest pause in seconds; S or AV = etiology of pause

Table 2. Results of Holter monitoring in 12 male long-distance runners: group B.

Athlete no.	Age	Slowest heart rate		SVPC (1)	VPC (2)	Pauses of 2 seconds		Pauses >2 sec (3)	AV block	
		Day	Night			Number/24 h	Etiology (3)		1st	2nd (4)
1	20	32	28	3	3	5	S	9/2.36/S (5)	–	–
2	21	35	34	–	8	1	S	–	PR 0.24	–
3	24	50	37	–	2	–	–	–	–	–
4	25	40	28	5	1	1	S	9/2.28/S (5)	PR 0.24	–
5	26	40	40	3	1 + VT (6)	–	–	–	–	–
6	40	36	32	65	5	–	–	–	PR 0.32	–
7	19	33	33	1	–	1	S	–	–	–
8	24	41	33	1	–	1	S	–	–	–
9	31	34	34	–	–	–	–	–	PR 0.36	–
10	24	38	29	–	17 + 2C (7)	1	S	1/2.12/S (5)	–	–
11	31	38	35	36	5 + VT (8)	–	–	–	–	–
12	30	70	70	–	2	1	AV	–	PR 0.48	6 M1
Number of athletes with abnormality				7	9	7		3	5	1

(1) SPVC: supraventricular premature contractions, number/24 hours
(2) VPC: ventricular premature contractions, number/24 hours
(3) S: pauses caused by sinus arrest or sino-atrial block; AV: pauses caused by AV block
(4) Number of episodes of Möbitz I (M1) and Möbitz II (M2) AV block, number/24 hours
(5) first number = number of pauses > 2 seconds; second number = length of longest pause in seconds; S or AV = etiology of pause
(6) One VPC and one run of 3 VPC at 110/min
(7) 17 VPC and 2 couplets of VPC
(8) 5 VPC and one run of 4 VPC at 135/min

episodes of AV Wenckebach and a PR interval of 0.34 sec. Athlete 5A had 10 blocked P waves in 24 hours and complained of minor dizziness. Athlete 11A had one blocked P wave and in athlete 24A we noted 6 sequences of AV Wenckebach. Athlete 12B (athlete No. 12 of group B) had 6 episodes of AV Wenckebach and a PR interval of 0.48 sec.

Supraventricular premature contractions occurred in 18 subjects (49%). They were frequent in 3 individuals (235/24 h in 4A; 65 in 6B; 36 in 11B).

Ventricular premature contractions (VPC) were present in 13 men (35%). Ventricular tachycardia or couplets were seen in 3 athletes (5B, 10B, 11B). In athlete 5B we found one run of 3 consecutive VPC at a rate of 110/min. Athlete 10B had 17 VPC/24 h and 2 couplets of VPC. In athlete 11B there was a run of 4 VPC at a rate of 135/min.

Discussion

In order to establish normal limits for a mean 24-h heart rate, minimal heart rate trends and pauses, 24-h ambulatory ECG recordings from 260 healthy subject 40–79 years of age were analyzed by Bjerregaard [3].

A total of 77 subjects (30%) had a pause (RR interval $\geq$1500 msec), but in only 12 (5%) did the pause exceed 1750 msec with the longest pause measuring 2040 msec. In 12 subjects the longest pause was caused by sinus arrest, and in nine cases a blocked atrial premature beat was thought to be present. Wenckebach AV block was seen in only two subjects.

Brodsky *et al.* [4] reported results of Holter monitoring in 50 male medical students. Fourteen subjects (28%) had sinus pauses of more than 1.75 sec. Only 2 subjects had pauses longer than 2 sec and the longest pause was 2.06 sec. Transient nocturnal type-1 second-degree AV block was noted in 3 subjects (6%). One subject had 17 episodes of second-degree AV block (type 1), 16 during sleep and 1 while awake. Pauses reached a maximum of 2.44 sec. Another subject had one episode of second-degree AV block (type 1) that occurred during sleep with a pause of 2.12 sec. One episode of second-degree AV block (type 1) occurred in one other student during sleep with a pause of 2.68 sec. Of 28 subjects (56%) having premature beats, only 1 (2%) had more than 100 such beats (141) in 24 hours. Of 25 patients (50%) having premature ventricular contractions, only 1 (2%) had more than 50 such contractions (86) in 24 hours.

Hanne-Paparo *et al.* [7] performed Holter monitoring in 32 athletes. Only one subject had intermittent type-1 second-degree AV block. The longest pause in this study was reported to be 1.68 sec.

Talan *et al.* [16] reported 24-h ECG recordings in 20 male long-distance runners. Compared with untrained males of similar age, the runners had slower heart rates, longer sinus pauses, and a higher prevalence of AV block. Runners and untrained males did not differ with respect to prevalence of ventricular

premature beats, R on T phenomena, ventricular couplets, or ventricular tachycardia. In only 2 runners was the longest waking sinus pause longer than 2 sec, in one case 2.55 sec. In seven runners the longest sleeping pause was longer than 2 sec and in two runners longer than 2.5 sec, the longest being 2.8 sec. Eight runners had one or more episodes of type-1 (Wenckebach) second-degree AV block.

Viitasalo *et al.* [17] obtained Holter data from 33 highly trained endurance athletes. Second-degree Wenckebach type block was observed in 8 athletes and second-degree block with Mobitz II-like pattern in three. Thirteen athletes had PP intervals exceeding 2 sec. The longest PP interval among athletes was 2.76 sec and among controls 2.6 sec.

Considering the maximal length of pauses reported by the authors quoted, we find 2040 msec [3], 2060 msec [4], 1680 msec [7], 2810 msec [16], 2760 msec [17] and 2500 msec (our data, group 2). Figures from a hospital population are quite different [6]. While 253 out of 2350 Holter recordings (10.7%) demonstrated pauses of 2 sec or more, 53 patients had ventricular asystole of 3 sec or longer.

Vasovagal syncope is a relatively frequent occurrence in young adults [2, 10, 15]. Sapire *et al.* [12] implanted pacemakers in 4 children with vasovagal syncope.

Increased vagal tone in highly trained athletes is described in subjects with first- and second-degree AV block at rest and syncope after exercise [11, 13]. In the patients treated by Rasmussen *et al.* [11], cerebral attacks due to excessive vagal tone were eliminated by considerable reduction of training activities. Among 126 top athletes, in whom an ECG was obtained during a random survey, Meytes *et al.* [8] found first-degree AV block in 11 subjects and Wenckebach's phenomenon in three. The heart block was found to be present only during seasons of intensive training and could not be demonstrated a few weeks after training had been reduced in intensity or stopped.

Ector *et al.* [5] reported 16 athletic patients, examined because of syncope, Stokes-Adams attacks, or both. This life-threatening condition required pacemaker implantation in 7 patients and 8 of the 9 other subjects became asymptomatic after stopping heavy physical training.

Young *et al.* [18] described his experience with 16 young patients, 6 female and 10 male. Known onset of Wenckebach and varying first-degree block was between 6 months and 17 years of age. Of eight patients followed up for 5 to 18 years, five have fixed complete heart block and three first-degree block. Of eight followed for 1 to 4 years, two have fixed complete heart block and the others varying first-, second- and third-degree block. He suggests the occurrence of Wenckeback block in 7 of 16 children and adolescents before the development of fixed complete heart block may be a phase in the natural history of the development of idiopathic heart block.

The normal athlete does usually not suffer from any discomfort, correlated with bradycardia and/or pauses. We believe that there is no reason for warnings against competitive sports. Sport per se is neither a life-threatening nor life-saving occupation. Recent literature, case reports and rumors tend to be somewhat

mythical [1]. In our athletes we found only minor abnormalities. This is in agreement with the experience of others [7, 17]. With respect to life expectancy we refer to Schnohr's study on longevity and causes of death in male athletic champions [14]. Information was obtained about 297 (96.7%) of 307 male athletic champions born in Denmark between 1880 and 1910. Mortality among the athletes was compared with the mortality in the general Danish male population. The ratio of observed to expected deaths was 0.61 in the life period from 25 to 49 years, 1.08 from 50 to 64 years, and 1.02 from 65 to 80 years. The male athletic champions had a significantly lower mortality than the general population before the age of 50 years; after 50 years of age the mortality was the same. The causes of death were the same as in the general population.

Occasional dramatic events during athletic activities should not mislead the clinician who must carefully evaluate differences between 'athletic patients' and normal athletes.

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Repolarization abnormalities

P. ZEPPILLI and N. ASPROMONTE

Introduction

Repolarization abnormalities (RA) have long represented a major problem for sports physicians. Since these ECG changes are usually observed in young, asymptomatic and well-trained athletes in the absence of any signs of ischaemic heart disease, they have been termed pseudo-ischaemic repolarization disorders.

Several classifications of RA have been proposed. Plas differentiated minor from major repolarization abnormalities and hypothesized that changes in the shape of the T wave and in polarity could be related to the degree of training [14]. Russian authors, first Butschenko [1] and Dembo [2] and more recently Dziak *et al.* [4] considered them to be an unequivocal expression of myocardial damage caused by overtraining of the heart, the so-call 'myocardial dystrophia'. In 1978, Strauzenberg *et al.* [16] proposed a clinical-electrocardiographic classification in which RA were divided into three categories, according to their response to exercise and/or vagolytic drugs. The first category, characterized by increasing RA during exercise, was considered to be an expression of cardiocirculatory asthenia due to infections, toxic reactions and overtraining. Type II abnormalities are identified by resolution or at least tendency to normalization with exercise or vagolytic drugs, and were considered to be benign phenomena attributable to the reversible vagotonic prevalence in athletes. Type III abnormalities were identified by their persistence on exercise and/or after administration of vagolytic drugs, and were considered to indicate an irreversible vagotonic prevalence.

Strauzenberg *et al.* were the first to attempt to provide a clinical framework for this problem based on the exercise stress test. Unfortunately, a major factor impeding this classification was the lack of routine echocardiographic investigation in the athletes examined. With the advent of widespread utilization of modern non-invasive diagnostic techniques, mainly echocardiography and nuclear imaging procedures, there has been a radical change in the diagnostic and prognostic approach to this problem.

Etiopathogenesis of repolarization abnormalities in athletes

From the theoretical standpoint, RA in untrained subjects can be correlated with

several types of condition: cardiac, including myocardial ischaemia, myocarditis or pericarditis, cardiomyopathy and mitral valve prolapse; neurogenic, including neurocirculatory asthenia, hyperkinetic heart syndrome, long QT syndrome, etc.; and miscellaneous, including electrolyte imbalances, drugs, hypoxia, endocrine disorders, etc. Nevertheless, many of these conditions are incompatible with physical exertion and are thus not seen in athletes, while others are very rare and can be easily excluded by simple clinical examination.

In 1982, in collaboration with the Sports Medicine Institute of Rome, we carried out a retrospective analysis of the etiopathogenic spectrum of RA in 98 athletes competing in various sports at different levels [22]. The athlete group was comprised both of subjects with RA detected during a routine survey and subjects referred for RA evaluation. The workup routinely included exercise testing, one- and two-dimensional echocardiography, and whenever appropriate, myocardial scintigraphy and/or invasive procedures such as coronary arteriography. Fifty-two athletes were free of demonstrable heart disease and were considered normal, however 6 of them (11.5%) had septal hypertrophy with a septal/free wall ratio greater than 1.3. Two athletes, one with septal hypertrophy and the other with a positive ECG stress test, were subjected to coronary angiography and ventriculography, negative in both cases. Thirty-seven had mitral valve prolapse (MVP), 5 with signs of hyperkinetic heart syndrome; 3 had hyperkinetic syndrome alone, 3 had non-obstructive hypertrophic cardiomyopathy (HCM) and 2 had suspected HCM; finally, one had moderate aortic stenosis.

MVP thus appears to be the most frequent condition associated with RA in athletes. In the majority of cases, ECG changes are represented by flat/negative T waves in the inferolateral leads with or without ST depression. RA usually increase in the orthostatic position and with hyperventilation, disappearing after administration of beta-blockers. In most cases they are normalized by exercise, but in agreement with observations by Engel *et al.* [5], in our study MVP was the most frequent cause of positive ECG stress tests in athletes.

HCM is an infrequent cause of RA in athletes [9, 11], however due to the important role of this disease in precipitating sudden death, it is essential that it be properly identified [10]. In the last 2 years, the apical variant [18] was the most frequent form of HCM seen in our laboratory [13, 22]. This is probably due to a more favourable clinical course of this form, and to a better exercise tolerance which allowed the affected athletes to engage in sports activity despite the disease. Fortunately, many subjects with apical HCM present very typical RA characterized by a giant negative T wave in precordial leads, facilitating identification of this disorder.

Echocardiography, in particular two-dimensional echocardiography, has thus allowed great advances in this field while posing new problems in interpretation. In our 1982 survey, 11.5% of athletes with RA and apparently normal hearts showed isolated septal hypertrophy. This correlation was also noted by Maron in 4 of 8 athletes examined [9]. Some of our athletes with RA and septal hypertro-

phy developed progressive septal or diffuse hypertrophy which remained unchanged after short detraining periods. Complete regression of echocardiographic and electrocardiographic findings suggestive of HCM after a 4-year detraining period has been noted by Oakley *et al.* [12] in an Olympic walker, and was seen in one of our patients [13]. Finally, in one patient with RA and 'very probable' HCM, after a 3-month detraining period we saw only minor changes in the electrocardiogram, despite a significant reduction in ST-T wave abnormalities and QRS voltages [22]. It thus appears that RA are secondary to cardiac hypertrophy in some athletes.

Along these lines, we note that Spirito *et al.* [15] found hypertrophy to be the most frequent cause of false-positive exercise ECG studies in athletes. It is reasonable to assume that some athletes may be prone to development of 'inadequate' septal or diffuse cardiac hypertrophy in response to training. A possible explanation for this phenomenon could be found in an asymmetrical distribution of myocardial beta-receptors prevailing in the interventricular septum and/or in an atypical beta-receptor response to training stimuli [3, 12, 17]. Another important factor may be the geometric arrangement of myocardial fibers [8]. Finally, it is also possible that training significantly influences the morphological and electrophysiological characteristics of HCM.

Pathophysiological mechanisms of repolarization abnormalities in athletes

In spite of these hypotheses, the vast majority of athletes with RA show no evidence of organic heart disease. In this group, repolarization is normalized by exercise or administration of beta-mimetic agents such as isoproterenol [19, 21]. Several pathophysiological mechanisms for 'idiopathic' RA have been proposed, some of which imply a close relationship between repolarization changes and the intensity of training [1, 2, 4, 16]. In our opinion, however, the well-documented spontaneous variability of such ECG abnormalities renders this hypothesis implausible. The possibility of myocardial damage or metabolic changes due to overtraining remain hypothetical [1, 2, 4]. A possibility of a pathogenic role of infectious foci has been stressed by some authors [16], but has never been acceptably demonstrated. A familial predisposition has also been proposed [6]. At present, a neuroadrenergic mechanism seems to be the most acceptable [20]. This hypothesis fits well with the spontaneous long-term changes in the repolarization phase, with the marked instantaneous variability in the ST-T wave in response to different stages and types of exercise, and with the possibility of pharmacologic reduction of similar RA with beta-stimulating or beta-blocking agents [21].

Prognostic evaluation of repolarization abnormalities in athletes

I shall briefly consider this point in terms of possible differential aspects of benign and pathological RA (Table 1). The former imply the absence of any organic heart disease demonstratable with non-invasive investigations, usually with marked spontaneous or induced variability, resolving with exercise and compatible with excellent physical performance. The latter are associated with organic heart disease, and sometimes with impaired or inadequate cardiovascular performance, are stable, and remain unchanged or worsen with exercise. It should be emphasized that there are still many cases where it is very difficult to define the frontier between the physiological and pathological RA. In such cases, a detraining period may be of some help to the cardiologist. In our experience, invasive procedures such as coronary arteriography are rarely warranted in asymptomatic athletes with RA, even if they are sometimes mandatory, at least in our country, due to medico-legal factors.

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Table 1. Differential aspects of benign and pathological repolarization abnormalities in athletes.

REPOLARIZATION ABNORMALITIES IN ATHLETES	
– NO SYMPTOMS	– cardiac SYMPTOMS
– variable ST-T changes	– fixed ST-T changes
– normalization on effort	– worsening on effort
– excellent physical performance (not absolute!)	– inadequate/deteriorated physical performance
– NO HEART DISEASE	– HEART DISEASE
⇩	(non-invasive evaluation) ⇩
FOLLOW-UP	RESTRICTION from sport

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Effects of intensive physical conditioning on cardiovascular parameters of high-level athletes

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Summary

The potential effect of short-duration intensive training on cardiac function was investigated in 18 endurance athletes, 9 marathon runners and 9 cross-country skiers. Electrovectorcardiogram, M-mode echocardiogram, maximal exercise testing and a 24-h Holter ECG were performed before and at the end of a 3-month span of intensive training. Among the cardiac parameters studied, the only statistically significant changes were, in skiers: prolongation of PR interval, increase in QRS duration, decrease in left maximal spatial voltage, increase in physical capacity and, in runners: increase in left posterior wall thickness over left ventricular (LV) diastolic diameter. However, most indices of left ventricular mass and function already exceeded the upper limits of normal at the first examination, especially in runners. The absence of clinically significant modification after intensive training indicates that these parameters reflect structural changes which cannot be further modified by short-term conditioning.

Introduction

Regular physical training such as that practiced by top-level athletes is associated with well-known modifications of cardiac anatomy and function [3, 9]. As compared with non-athletes, indices of left ventricular mass and function are modified. Athletes, especially endurance athletes, have an increased cardiothoracic ratio on chest X-ray, higher voltages on the electrocardiogram, higher left ventricular wall thickness and cavity dimensions on the echocardiogram. These changes are proportional to the duration of sports practice and they are not highly dependent on the type of sport. By definition, athletes have an increased physical capacity demonstrated by higher maximal workload with higher oxygen consumption ($\dot{V}O_2$ max) during maximal exercise testing. They have a lower resting heart rate and a much higher maximal systolic ejection volume than untrained subjects. What remained to be investigated was the potential effect of short-duration intensive training on cardiac parameters in well-conditioned athletes. To this end, we performed a series of cardiac tests in 18 endurance athletes before and at the end of a 3-month span of intensive training as preparation for national

and international sport contests. The purpose of this study was to see whether this intensive short-term specific training could significantly modify cardiac parameters and, therefore, contribute to a further increase in physical performances.

Methods

Study population

We studied 18 young endurance athletes divided into 2 groups according to the type of sport. Group 1 consisted of 9 marathon runners and group 2 of 9 cross-country skiers. Table 1 shows that there were no significant differences between the two groups in terms of age, height and weight. All these subjects were top-level athletes who had undergone specific training for an average of 8 years. The runners were able to finish a marathon race in an average of 2:35, whereas the average time for the skiers was 1:40 for 30 km and 2:35 for 50 km.

Cardiac tests

Non-invasive tests were used in each athlete to study various cardiac parameters which generally differ from those of untrained normal subjects [10]. Each test was performed twice, the first test before intensive training and the second at the end of the 3-month period of specific training or 8 days before the sport contest.

Electrovectorcardiogram (ECG-VCG)

The standard 12-lead ECG was recorded by means of a 3-channel automatic electrocardiograph and analyzed visually. The Frank VCG was recorded on digital magnetic tape and automatically analyzed by the Louvain VCG computer program [1].

Echocardiogram (ECHO)

The M-mode ECHO was recorded using an IREX system. The tracings were manually marked in accordance with the AHA recommendations and quantitative parameters were calculated by means of a computer program.

Table 1. Characteristics of the study population.

	GROUP 1		GROUP 2	
	9 MARATHON RUNNERS		9 CROSS-COUNTRY SKIERS	
	Mean	Range	Mean	Range
Age (years)	28.4	(23–41)	29.0	(20–52)
Height (cm)	168.6	(163–180)	177.6	(169–182)
Weight (kg)	63	(51–75)	70	(64–90)

Maximal exercise-test (MAX test)
The MAX test was performed on a bicyle ergometer with increments of 20 Watts each min and with a pedaling rate of 60 cycles/min. The Frank orthogonal XYZ leads were continuously recorded and displayed. At the end of each min, at rest, during exercise and during the first 5 min of the recovery, a digitized sample of the ECG was recorded for further computerized analysis; blood pressure was also monitored during the test. At the end of the test, the $\dot{V}O_2$ max was measured by the gas exchange method. The $\dot{V}O_2$ max, from which the physical capacity is derived, can also be computed by means of a normalized protocol.

Holter ECG-monitoring (HOLTER)
The 24-h Holter ambulatory ECG was obtained in each subject using an Avionics® system with examination of the tapes by a cardiologist. A training session was included for each recording and special care was taken for proper electrode and cable placement and skin preparation in order to avoid as much interference by muscle noise as possible.

Statistical analysis
Within-subject differences between the two series of examination (before and after training) were analysed by means of a paired Student's t-test. Differences between the two groups of athletes during each series of examination were analysed by means of an unpaired Student's t-test. Values are means ± SD.

Results

Table 2 shows the values of ECG-VCG parameters in the two test series for each group of subjects. Only statistically significant differences ($p<0.05$) are indicated.

The PQ interval, which indicates the duration of atrioventricular conduction, was slightly increased (from 160 to 169 msec) in test 2 only in skiers. The PQ interval was larger in runners than in skiers, especially in test 1, but the difference was not significant.

The QRS duration was not modified in runners whereas in skiers, it increased from a mean of 979 msec to 100 msec after training ($p<0.05$). In test 2, the difference between the skiers and the runners (100 vs. 92 msec) became significant ($p=0.03$). Values for all athletes fell within the normal range for this parameter (80 to 116 msec), however in many cases they were at the upper limit of normalcy.

The QTc interval, or QT interval corrected for heart rate, indicates the duration of ventricular depolarization + repolarization. The mean value of this parameter was at the upper normal limit in both tests in runners whereas it was lower in

skiers (NS). There was a slight increase in runners from test 1 to test 2 (NS). Individual values in skiers showed an increase in QTc in test 2 in 5 subjects with a decrease in 4 others. The mean value of QTc was higher in runners than in skiers, especially in test 1 (426 vs. 401 msec, $p \simeq 0.06$).

The left maximal spatial voltage of QRS indicates the magnitude of potentials generated by the depolarization of the left ventricular free wall, independent of heart position and thoracic morphology. The mean value of this parameter was higher in runners than in skiers but the difference was significant only in test 2 (2.59 vs. 2.02 mV). The modification after training was different in the two groups of athletes: it slightly increased in runners (2.54 to 2.59 mV, NS) whereas it showed a significant decrease in skiers (2.17 to 2.02 mV, $p = 0.03$). As compared with the normal values for their age and sex [7], several athletes, especially the runners (5 out of 9 subjects), exceeded the upper normal limit for this parameter.

The mean QRS vector represents the integral of the voltages and duration of individual vectors of the whole ventricular depolarization. Its value is expressed in mV · sec or μV · msec. Again, the mean value in both tests was higher in runners than in skiers, but the difference was significant ($p<0.02$) only in test 2 (55 vs. 46 mV · sec). This value showed a slight increase after training in runners (51 to 55) whereas there was a slight decrease in skiers (47 to 46). Average values for the two groups were within normal limits however some individuals exceeded

Table 2. Electrovectorcardiographic parameters.

	MARATHON RUNNERS		SKIERS	
	Test 1	Test 2	Test 1	Test 2
PQ interval (msec)	174 ± 27	172 ± 25	160 ± 29 ↔	169 ± 32
			$p<0.01$	
QRS duration (msec)	95 ± 12	92 ± 10	97 ± 5 ↔	100 ± 6
			$p<0.05$	
			$p \simeq 0.03$	
QTc interval (msec)	426 ± 40	431 ± 31	401 ± 28	411 ± 31
Left max spatial voltage of QRS (mV)	2.54 ± 0.64	2.59 ± 0.56	2.17 ± 0.4 ↔	2.02 ± 0.42
			$p = 0.03$	
			$p = 0.04$	
Mean QRS vector (mV · sec)	51 ± 17	55 ± 19	47 ± 5	46 ± 11
			$p<0.02$	
Max spatial T vector (mV)	0.67 ± 0.26	0.67 ± 0.17	0.65 ± 0.13	0.71 ± 0.22
Heart rate (beats/min)	57 ± 13	59 ± 12	63 ± 10	61 ± 10

Test 1 = before the training period.
Test 2 = at peak physical conditioning.

the upper boundary. For instance, a 25-year old runner had a mean spatial QRS magnitude of 86 mV · sec while the upper normal limite was 66 mV · sec.

The maximal spatial T vector represents the magnitude of potentials generated by the ventricular repolarization. There was no intra-individual difference, nor was there a difference between the two groups. The mean values were within normal limits for this age group however the upper limit was exceeded in 5 cases.

The resting heart rate was not significantly modified from test 1 to test 2 in either group of athletes. The runners had a slightly lower heart rate at rest than did the skiers (NS). Table 3 shows the results of the 24-h Holter monitoring.

The mean heart rate over the 24 hours remained the same in runners after training whereas it decreased in skiers; this difference was not significant. In test 1, the mean heart rate was lower in runners than in the skiers but the difference decreased in test 2.

The minimum hourly heart rate was unchanged and equivalent in the two groups and in the two tests.

The maximal hourly heart rate increased from 133 to 142 beats/min in the runners whereas it decreased from 136 to 122 beats/min in the skiers. After training, the runners reached a higher maximal heart rate than the skiers but the difference was not significant.

The echocardiographic (ECHO) parameters studied included: septal and left posterior wall systolic thickening, left ventricular (LV) mass and LV mass index, ratio of LV posterior wall thickness/end-diastolic LV diameter, end-diastolic LV diameter, end-systolic LV diameter, LV fractional shortening and the ratio of left atrial/aorta diameters. Among these parameters, only the ratio of left ventricular wall thickness/LV diastolic diameter was different in test 1 between the two groups of athletes; 0.15 ± 0.02 in the runners and 0.17 ± 0.08 in the skiers ($p \simeq 0.02$). In test 2, this ratio increased only in runners (from 0.15 ± 0.02 to 0.17 ± 0.08, $p < 0.04$), and the difference between the two groups was thus abolished in test 2. In general, all indices of left ventricular mass and function, already above the upper normal limit in test 1 in most athletes, were not further modified in test 2 after intensive training.

Table 3. Holter-ECG.

	MARATHON RUNNERS		SKIERS	
	Test 1	Test 2	Test 1	Test 2
Mean Heart Rate (beats/min) – over 24 hours –	66 ± 6	67 ± 6	73 ± 5	69 ± 7
Minimal Heart Rate (beats/min) – per hour –	49 ± 2	48 ± 5	50 ± 7	49 ± 3
Maximal Heart Rate (beats/min) – per hour –	133 ± 21	142 ± 23	136 ± 11	122 ± 22

The maximal exercise test revealed a similar maximal workload and maximal heart rate at peak exercise in the two testing series. The runners had a lower maximal heart rate than the skiers in the two tests (174 ± 9 vs. 183 ± 15 in test 1 and 172 ± 10 vs. 181 ± 13 in test 2) but the difference was not significant. A 35-year old skier could reach a maximal heart rate of 200/min. Another 25-year old skier reached a maximal workload of 440 Watts. A slight and non-significant increase of $\dot{V}O_2$ max was found in the two groups between test 1 and test 2 (4.22 ± 0.57 to 4.33 ± 0.45 l/min in runners and 4.13 ± 0.45 to 4.28 ± 0.9 in skiers). In runners, the physical capacity, measured as a percentage of the normal value, was $139 \pm 21\%$ and $141 \pm 17\%$ in tests 1 and 2 respectively. Corresponding figures in skiers were 135 ± 17 and 142 ± 20 in tests 1 and 2, respectively ($p \simeq 0.03$).

Discussion

Among the numerous cardiac parameters studied, relatively few showed significant changes before and after this short-term physical training.

Among ECG-VCG parameters only the increase in the PQ interval, the QRS duration and the decrease in left maximal spatial voltage in skiers were statistically significant. There was no intra-individual difference for the other parameters. Marathon runners generally had higher values for the PQ and QTc intervals and the left maximal and mean QRS spatial vectors than skiers. Conversely, resting heart rate and QRS duration were lower in runners than in skiers. On the average, the two groups of athletes were close to the upper normal limit for most parameters, and only the mean left maximal spatial QRS vector was clearly outside the upper limit of normal. In some individuals however, some parameters were outside normal limits. These 'abnormalities' were more frequent in runners than in skiers. For instance, the QTc interval was prolonged in 78% of the runners and in 67% of the skiers. The left maximal spatial QRS vector exceeded the upper normal limit in 56% of the runners but in none of the skiers. There was a minor right ventricular conduction delay in 33% and 22% of the runners and skiers, respectively. Other abnormalities seen in runners and absent in skiers were: anterior displacement of QRS loop (44%), T loop modification (44%), various rhythm disturbances (e.g. ectopic atrial rhythm) (22%) and 'pseudo-necrosis' Q waves (22%). A completely normal ECG was found in 56% of the skiers and in only 11% of the runners. Various electrovectorcardiographic abnormalities in athletes have been underscored by several previous studies [2, 4, 6, 9]. The most frequent features (i.e. high voltages, prolonged QTc interval and minor right ventricular conduction delay) are probably related to the increased left ventricular wall thickness. It is interesting to note that some of the other features (anterior shift of QRS, posterior shift of the T loop and Q waves) have been described in patients with hypertrophic cardiomyopathy.

The 24-h Holter ECG showed no significant change in mean heart rate or minimum and maximum hourly heart rate in the two testing series. Among special features, we observed: first-degree AV block in one runner and three skiers, second-degree AV block (Mobitz type-I) in one skier and one runner, sinus pause or SA block in one runner (3.6 sec at night), sinus bradycardia <40 beats/min in two skiers (29 beats/min in one subject at night), atrioventricular junctional rhythm in three runners, premature ventricular complexes, isolated in one and repetitive in one other runner and isolated premature atrial complexes in one runner. The J point-ST segment was elevated in 78% of the cases, both in runners and skiers (maximum 0.4 mV), which could represent non-specific ST-T changes. These findings are in accordance with previous results of Holter ECG monitoring of athletes [5, 8]. One subject showed a more impressive ventricular arrhythmia (numerous PVCs). The same subject had an ECG-VCG suggestive of hypertrophic cardiomyopathy, but without typical features on the echocardiogram.

The ECHO parameters and the results of the MAX test were not significantly altered before and after physical training in the two groups of athletes. In both groups, the percentage of systolic thickening of the septum and LV posterior wall and the left ventricular mass indices exceeded upper normal limits. After 3 months of intensive physical training, there was no statistically significant increase of these indices of left ventricular function and of left ventricular thickness and cavity dimensions. Similarly, the maximal workload, maximal heart rate and the $\dot{V}O_2$ max were not significantly increased after the training period. While an increase in the level of physical capacity was seen only in skiers, capacity was already very high at the time of the first examination and, therefore, it was difficult for this short training period to further enhance physical performances.

Conclusions

This 3-month period of intensive training in top-level endurance athletes had no marked influence on most of the cardiac parameters studied. These parameters probably reflect structural changes in cardiac anatomy and function which have developed over the years, due to regular conditioning, and which cannot be further modified by a short-term intensive training.

A practical consequence of our findings is that one cannot rely on these non-invasive cardiac tests to monitor the training of athletes and to decide whether this training is well-adapted and appropriate for a given athlete. This observation is in accordance with recent studies which have questioned both the reliability of the distinction between 'endurance' and 'resistance' heart and the wisdom of using cardiac tests such as ECG or VCG to judge the level of training – overtraining or undertraining – in individual athletes.

On the other hand, the fact that several ECG, VCG and ECHO parameters

were outside of normal limits in athletes implies that caution is required for the interpretation of diagnostic significance of these procedures in case of development of functional symptoms in these subjects. False-positive diagnoses of left and right ventricular hypertrophy, of hypertrophic cardiomyopathy and even of coronary artery disease could be made if one is unaware of these characteristics of the 'athletic heart syndrome'. Further studies are required for evaluation of changes in these cardiac parameters during the full lifespans of athletes, in relation with the possible advent of organic cardiovascular disease.

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Electrocardiograms of endurance athletes

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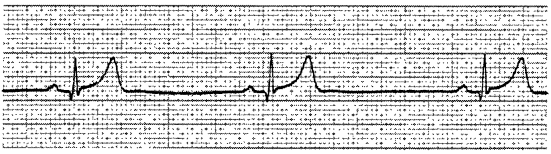

Figure 1. Sinus bradycardia. Lead II. Regular sinus rhythm at a rate below 50 per min (35/min).

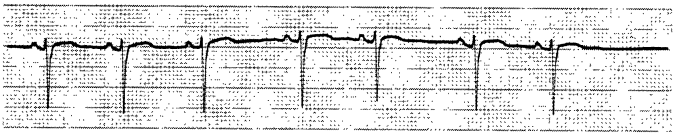

Figure 2. Non-phasic sinus arrhythmia. Lead V_1. Irregular sinus rhythm at a rate less than 100 per min, in which the cycle lengths vary by 10 percent or more; the heart rate bears no relation to the respiratory cycle.

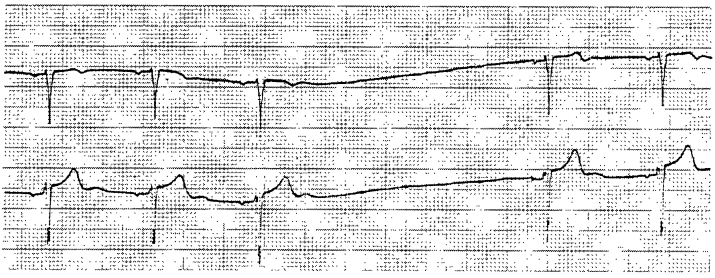

Figure 3. Sinus arrest; atrial escape beat. Leads V_1, V_2. The sinoatrial node fails to initiate an impulse at the expected time after three normal beats; the sinus pause is terminated by one escape beat of an ectopic atrial pacemaker, after which sinus rhythm resumes. The duration of the pause is 2.84 sec.

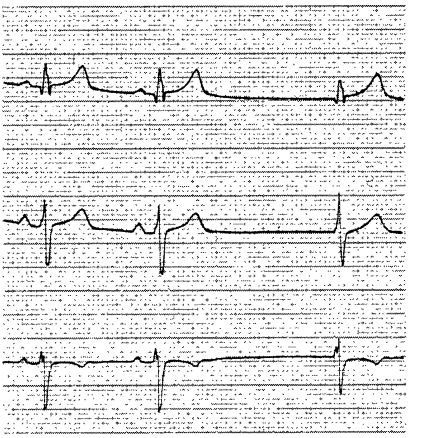

Figure 4. Sinus arrest; AV junctional escape beat. Leads I, II, III. After two normal beats a sinus impulse fails to appear and an AV junctional escape beat occurs.

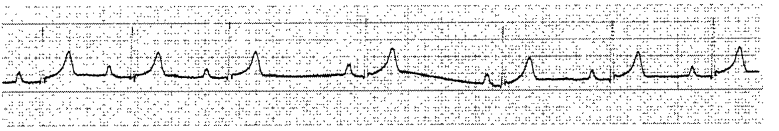

Figure 5. Sinus arrest; atrial escape rhythm; first-degree AV block. Lead II. After three sinus beats with first-degree AV block (PR>0.20 sec), a sinus impulse fails to appear; during the pause, two atrial escape beats occur, after which sinus rhythm resumes.

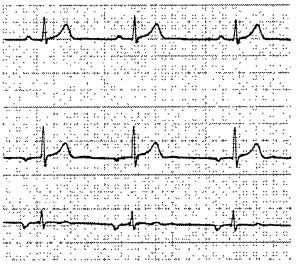

Figure 6. Coronary sinus rhythm. Leads I, II, III. The P waves are inverted in leads II and III (and in aV_F); the PR interval is 0.12 sec or more (0.18 sec).

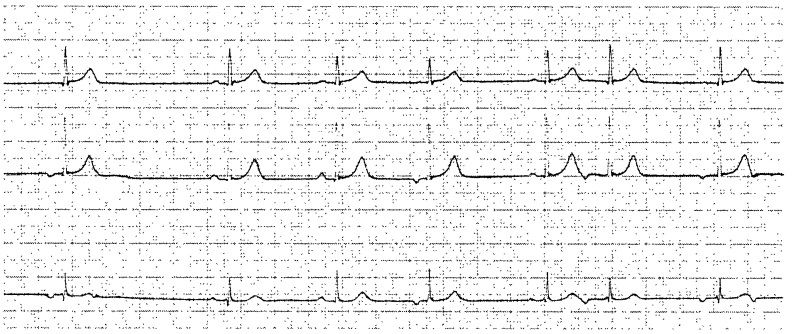

Figure 7. Wandering pacemaker. Leads I, II, III. The pacemaker shifts from beat to beat. The form of the P wave and the duration of the PR interval vary. The heart rate is less than 100 per minute. The 6th beat is probably a supraventicular premature beat.

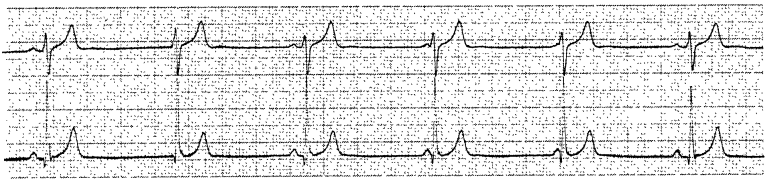

Figure 8. Atrioventricular dissociation. Leads I, II. The first and last beat are normal sinus beats. In the others different pacemakers control the atria and ventricles, so that they beat independently: the atria are under the control of the SA node, the ventricles under the control of a pacemaker in the AV junction (note the slightly different QRS complex from the sinus beat); the P waves are of normal contour and bear no fixed temporal relationship to the QRS complexes; the ventricular rhythm is regular and approximately equal to the atrial rate so that the AV node is refractory when sinus impulses reach the node.

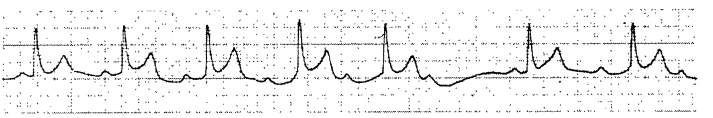

Figure 9. Second-degree AV block, Mobitz type I (Wenckebach type). Holter monitoring. There is progressive prolongation of the PR interval in successive beats until a ventricular complex drops out (after the 6th P wave).

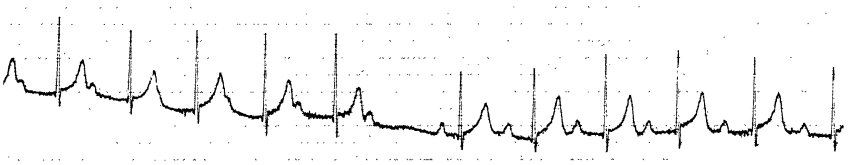

Figure 10. Blocked P wave. Lead II. A ventricular beat is dropped after the 6th P wave. The dropped ventricular beat is preceded by beats with a constant but prolonged PR interval (0.44 sec). The PR interval following the ventricular pause is shorter, prolongs from the 1st to the 3rd beat after the pause and then remains constant at 0.36 sec.

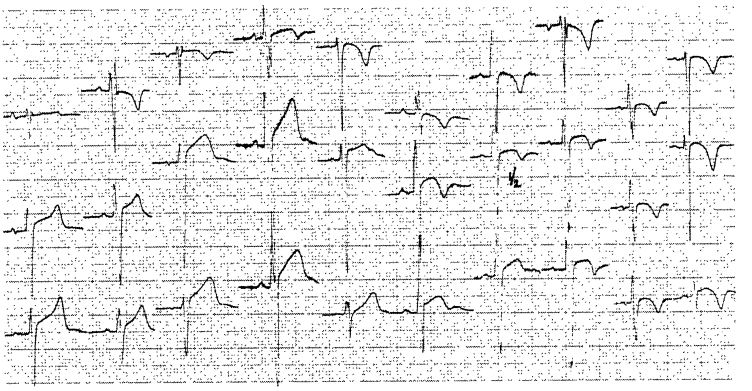

Figure 11. Right precordial leads V_1–V_3 in athletes. Note the variable QRS pattern in lead V_1. The ST-T segments show variable combinations of ST elevation (with upward concavity to convexity), and upright, diphasic or inverted T waves.

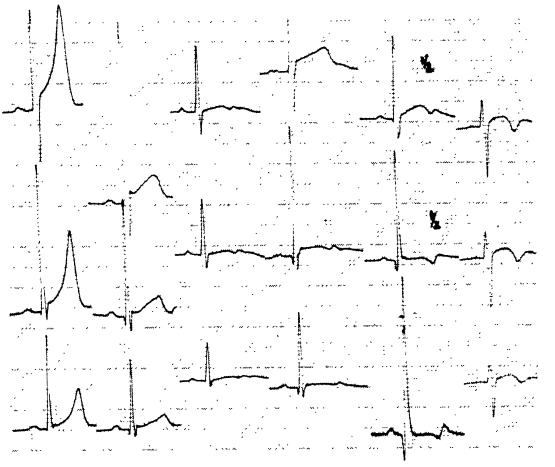

Figure 12. Left precordial leads V_4–V_6 in athletes. Note the high R wave in some athletes and the variable pattern of the ST-T segment.

§2. ECHOCARDIOGRAPHY IN ATHLETES

Echocardiographic evaluation of the heart of athletes: cross-sectional and longitudinal observations

R. FAGARD

Summary

Dynamic endurance training is associated with an increased left ventricular internal diameter and a more or less proportional increase in wall thickness. An isometric component in the sports activity will increase the ratio of wall thickness to internal radius, provided the activity is of sufficiently long duration. Left ventricular structure varies with the training state. Finally, although some significant differences in left ventricular function are observed in athletes compared with non-athletes and among athletes according to the training period, there is no evidence of any detrimental effect of training on left ventricular function.

Introduction

Echocardiography was introduced in the study of the hearts of athletes more than a decade ago and numerous studies have been published since then. What have we learned from these reports? Two types of observations will be covered in the present survey, with emphasis on the left ventricle (LV): 1) cross-sectional comparison of the hearts of athletes and non-athletic control subjects, and 2) the effects of training and detraining on the athlete's heart.

What might we expect? Figure 1 is a working diagram. At birth the human left ventricle has a certain internal diameter and there is a certain proportionality between left ventricular wall thickness (h) and the internal radius (R). As the child grows R increases in parallel with the volume load on the heart, and the h/R ratio appears to remain fairly constant from birth to adulthood. Dynamic endurance training, e.g. long-distance running, creates a further volume load on the heart like that of aortic or mitral insufficiency. This can be considered an extension of the normal growth process and therefore should lead to a further increase in left ventricular internal diameter with a proportional increase in wall thickness, thus keeping systolic left ventricular wall stress constant [7]. This type of hypertrophy is called eccentric left ventricular hypertrophy. On the other hand, strength training, such as weight lifting, raises blood pressure, at least during the activity. In accordance with findings in hypertension and aortic stenosis, this could lead to concentric left ventricular hypertrophy, i.e., unchanged

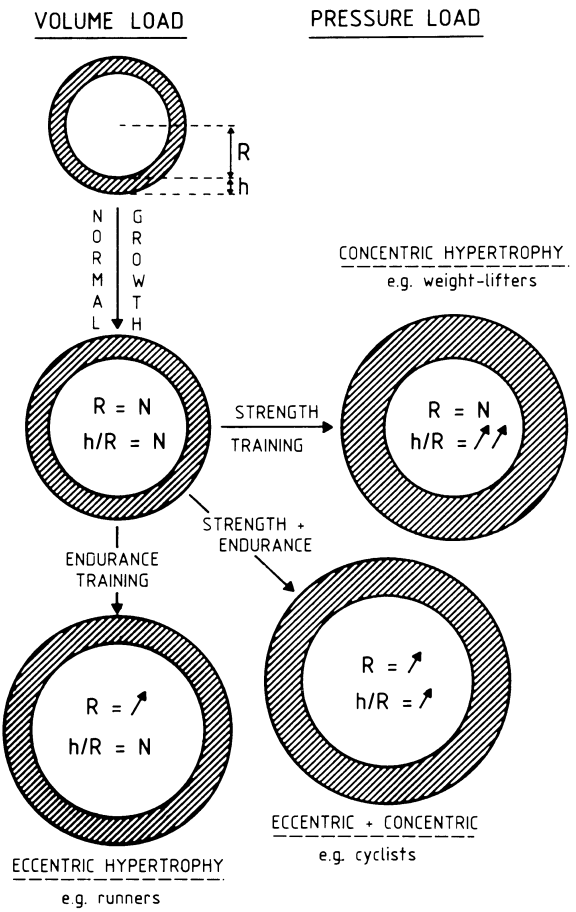

Figure 1. Left ventricular hypertrophy in sports: working diagram. See text for explanation.

LV internal radius and increased wall thickness. Sports such as cycling which involve both dynamic endurance and strength efforts could have the dual effect of augmenting LV internal radius and disproportionately increasing wall thickness, so that the h/R ratio also increases. Do the facts confirm these theoretical considerations and expectations?

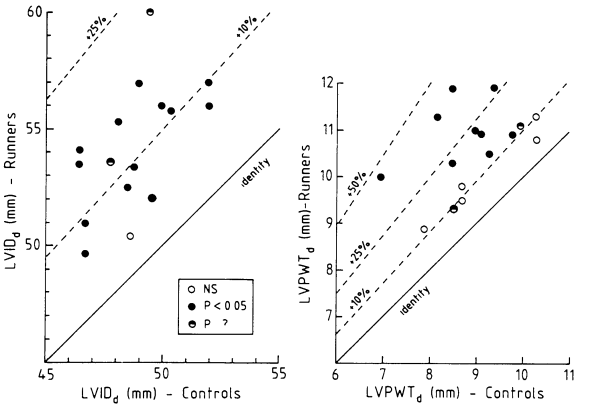

Figure 2. End-diastolic left ventricular internal diameter (LVIDd) and posterior wall thickness (LVPWTd) in runners (ordinate) and control subjects (abscissa). Each point represents the average for a group of athletes and controls.

Cross-sectional comparison of athletes' and non-athletes' hearts

A. Left ventricular structure

1. Long-distance runners

Figure 2 summarizes data on end-diastolic left ventricular internal diameter (LVIDd) and posterior wall thickness (LVPWTd) in 16 groups of runners and control subjects culled from 14 studies [5, 6, 8–10, 12–19, 21]. Each point represents an average, with the value for athletes on the ordinate and the value for the controls on the abscissa. This graphic arrangement has the advantage of not only comparing the athletes with the controls, but also taking the differences in methodology among the various investigations into consideration. The wide range of values observed in the controls, for instance, strongly suggests such differences.

All the studies but one [6] found a larger LVIDd in the athletes, so it would seem fair to conclude that the LVIDd of runners is greater than that of non-athletes, consistent with the theoretical expectations. Also, the LV posterior wall was significantly thicker in the runners than in the controls in most of the studies. The important variable, however, is the ratio of wall thickness to internal radius (h/R). Unfortunately, only two studies reported on this ratio. Fagard *et al.* [5] reported a mean value of 0.41 in runners, which was not significantly different from that of control subjects (0.37), whereas Sugishita *et al.* [18] calculated an inverse ratio (R/h) of 2.6 in runners versus 2.7 in non-athletes (NS). Finally, the ratio of septal thickness to posterior wall thickness did not, on average, vary significantly from 1.

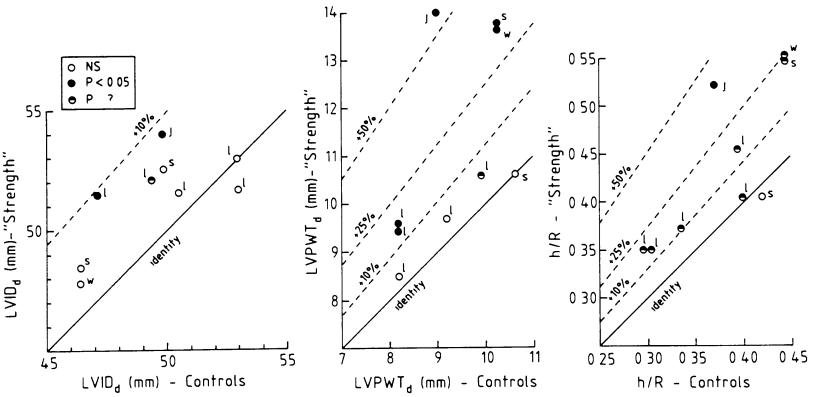

Figure 3. End-diastolic left ventricular internal diameter (LVIDd) and posterior wall thickness (LVPWTd) and the ratio of wall thickness to LV internal radius (h/R) in strength-trained athletes (ordinate) and control subjects (abscissa). Each point represents the average for a group of athletes and controls. The h/R data indicated by ◓ were calculated using the averages of LVID and wall thickness from the various studies. Abbreviations: j: judokas; l: weightlifters; s: shotputters; w: wrestlers.

The observations in long-distance runners do, therefore, reflect the development of eccentric LV hypertrophy. The increase in LV wall thickness, which is proportional to the enlarged LV internal diameter, together with unchanged blood pressure [3], results in similar systolic LV meridional wall stress in runners and non-athletes alike [5]. It has been suggested that the development of eccentric hypertrophy in cardiac patients with volume overload on the heart, such as is engendered by aortic or mitral insufficiency, serves to keep systolic wall stress constant [7].

Other cardiac dimensions are not discussed in detail in the present survey, but runners usually also present increased left atrial and right ventricular diameters.

2. Strength-trained athletes

Figure 3 summarizes the observations for 9 groups of strength-trained athletes from 7 studies, i.e., 5 groups of weight lifters [10, 11, 16, 17], 2 groups of shot-putters [12, unpublished personal observations], 1 group of wrestlers [12], and 1 of judokas [18]. The results are more variable. LVIDd in athletes and control subjects was identical in most studies, but some investigators found a significant 10% difference between athletes and controls. In some studies LVPWTd was not significantly different in the strength-trained athletes and controls, but in others the posterior wall was significantly thicker – by up to 50%. The h/R ratio was elevated in judokas [18], similar in shot-putters and controls (personal observations), and not reported in the other studies. Figure 3 includes a summary of the

observed or calculated h/R ratios in these various groups of athletes. In most studies the average ratio of septal thickness to posterior wall thickness was close to 1; the findings of Menapace *et al.* [11], who reported a significantly elevated ratio, were the exception.

It may be concluded that, despite theoretical expectations, concentric hypertrophy, i.e., unchanged LV internal diameter and increased wall thickness, is not a consistent finding. However, there are various reasons for these discrepancies. First, the athletes studied (weight lifters, shot-putters and wrestlers) were engaged in different sports. Moreover, it should be noted that the data are not consistent even within a given sport. Second, the athletes' training programs were mixed. So-called 'strength-trained athletes' may also run, but few studies gave exact details of the athletes' activities. For example, resting heart rate was lower in the wrestlers and in one group of weight lifters than in the control groups [10, 12, 18]. Finally, static isometric activity is of variable but often brief duration. Therefore the stimulus for hypertrophic development, i.e., the increase in blood pressure, is usually of short duration and does not necessarily lead to thickening of the wall, in contrast to the continuous pressure load in aortic stenosis and hypertension.

It thus follows that one should expect an increased ratio of wall thickness to internal radius when the isometric activity is of sufficiently long duration. Cyclists, for example, whose training and performance consist of mainly isotonic work by the legs but isometric work by the arms and upper body for many hours a day during the competitive season, should present an increased internal diameter and a higher h/R ratio. This is what Fagard *et al.* [5] observed in highly competitive Belgian cyclists. LVIDd averaged 55.2 mm in cyclists and 49.5 mm in controls, LVPWTd was 12.7 and 9.8 mm, respectively, and h/R, 0.45 and 0.39 ($p<0.05$). Figure 4 is an example of the echocardiogram of a cyclist.

3. Conclusions

From the cross-sectional observations in athletes and controls it can be concluded that dynamic endurance training leads to eccentric LV hypertrophy and that an isometric component in the athletic activity may cause a disproportionate increase in LV wall thickness when the stimulus is of sufficiently long duration. It is unlikely that mere strength training, involving only brief bursts of isometric activity, causes cardiac adaptations.

B. Left ventricular function

Figure 5 summarizes the reported data on fractional shortening of the LV internal diameter ($\triangle$LVID) or ejection fraction (EF) in runners, strength-trained athletes and control subjects. Most of the values obtained for athletes were similar to those for control subjects [5, 9, 11, 13, 18, 19, 21], but some studies reported a

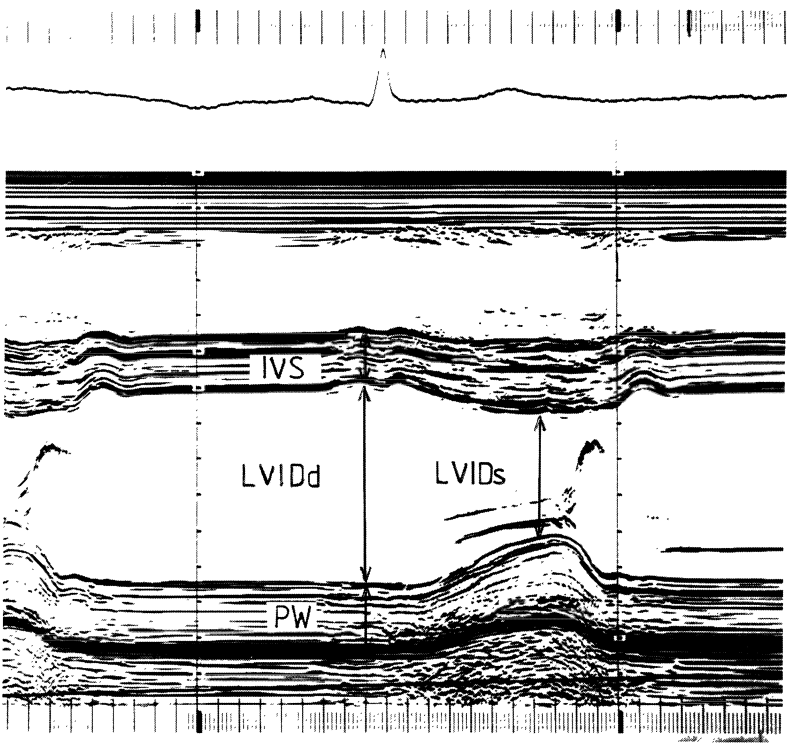

Figure 4. The M-mode echocardiogram of a cyclist. Abbreviations: IVS: interventricular septum; PW: posterior wall; LVIDd: left ventricular internal diameter at end-diastole; LVIDs: left ventricular internal diameter at end-systole.

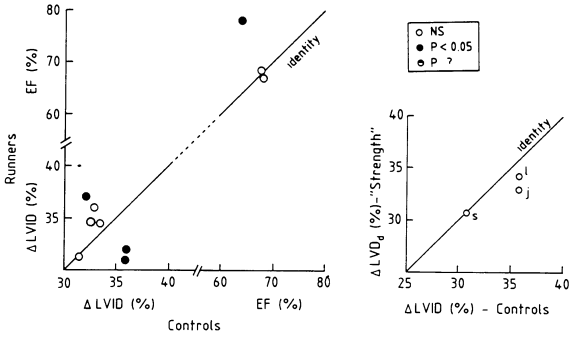

Figure 5. Fractional shortening of left ventricular internal diameter (△LVID) or ejection fraction (EF) in runners, strength-trained athletes (ordinate) and control subjects (abscissa). Each point represents the average for a group of athletes and controls.

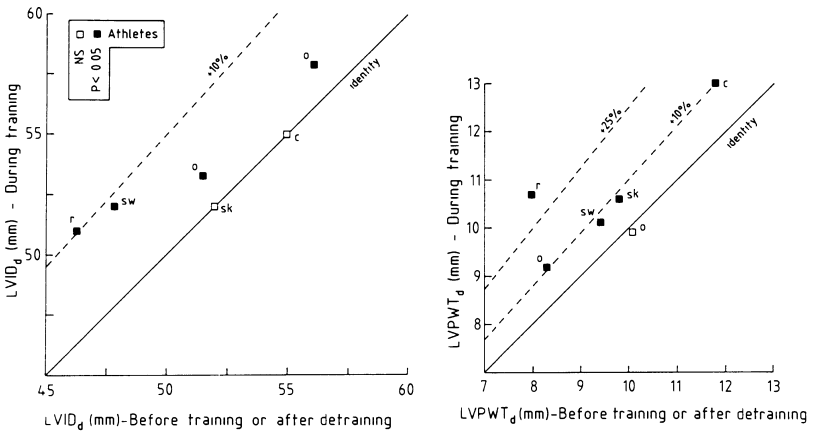

Figure 6. End-diastolic left ventricular internal diameter (LVIDd) and posterior wall thickness (LVPWTd) in athletes during training (ordinate) and before training or after detraining (abscissa). Each point represents the average results of a group of athletes. Abbreviations: c: cyclists; o: oarsmen; r: runners; sk: cross-country skiers; sw: swimmers.

slightly higher [8, 14] or a slightly lower [6, 18] value in runners. However, these values were still within normal limits. Also, investigations of other LV functional indices, such as the peak velocity of change of the LVID and the displacement of the LV posterior wall endocardium during systole and during relaxation, yielded no significant differences in runners compared with controls [5]. One should therefore not be concerned about the possible detrimental effects of dynamic endurance or strength training on left ventricular function.

Training and detraining of athletes

Four studies reported on the hearts of six groups of athletes – cross-country skiers [1], cyclists [4], swimmers [2], runners [2], and two groups of oarsmen [20] – before and during training or after detraining. Maximal oxygen uptake was found to be 8–15% higher, on average, during the training period. As shown in Figure 6, LVIDd was significantly larger during training than in the rest period in the runners, swimmers and oarsmen but not in the cyclists and cross-country skiers; the LV posterior wall was thicker during training in all groups except one group of oarsmen. LV mass or cross-sectional wall area increased significantly with the shift from the resting to the competitive season [2, 4], and was associated with significant electrocardiographic voltage changes when the latter were studied [4, 20].

These studies strongly suggest that training per se has an effect on left ventricu-

lar structure. The diversity of the sports activities in which the athletes participated does not allow further conclusions about the type of adaptation involved. The data do indicate that cardiac adaptations to training are reversible, but they cannot, of course, reveal whether such adaptations are completely reversible. Also, it is still not known if the athletes' hearts differed from those of control subjects before training began.

Left ventricular function as assessed by fractional shortening of the LV internal diameter or the ejection fraction was unaffected by training in the oarsmen, swimmers and runners but slightly lower in the rest period (or higher during training?) in cyclists and cross-country skiers.

Acknowledgement

We gratefully acknowledge the secretarial assistance of R. Nuyts.

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Left ventricular function in athletes: analysis of relaxation

T. GILLEBERT, F. RADEMAKERS and D. BRUTSAERT

Summary

Hypertrophy of the left ventricle (LV) is induced by overload and modulated by neurohumoral factors. Different types of overload will induce different adaptational mechanisms at the structural and at the biochemical level. As a consequence the athlete's LV can be distinguished from the pathological LV in its contraction and relaxation properties. Relaxation of the human LV is determined by loading conditions and by dissipation of activation (inactivation). These two determinants are modulated by spatial and temporal non-uniformity. From the analysis of LV relaxation marked differences can be observed in the mechanisms underlying impaired LV function in pathological hypertrophy and the supranormal LV function in athlete's hypertrophy. A faster relaxation is a teleologic adaptation to training since it allows more complete and earlier LV filling at rapid heart rates, favouring both an increase in stroke volume and a decrease in LV filling pressures during exercise. Cardiac adaptation to training include hypertrophy, enhanced contractility as well as enhanced relaxation.

When a load is *acutely* imposed on the left ventricle (LV), pump function is maintained by increased contractility and heart rate, and by enhanced coordination of myocardial activity (uniformity) [1]. If these mechanisms fail, LV filling pressure rises and myocardial performance will increase according to the Frank-Starling relationship, independently of changes in contractility.

In the presence of a *chronic* load, pump function is maintained by adaptive mechanisms at the structural and at the biochemical level. These mechanisms will be analysed for their consequences on LV relaxation.

A. Triple control of relaxation in the intact left ventricle

In analogy to the performance during contraction, relaxation of the intact heart is governed by the continuous interplay of the sensitivity of the contractile system to the prevailing load (*load dependence*) and the dissipating activation (*inactivation*). This double control of relaxation is modulated by the regional and temporal

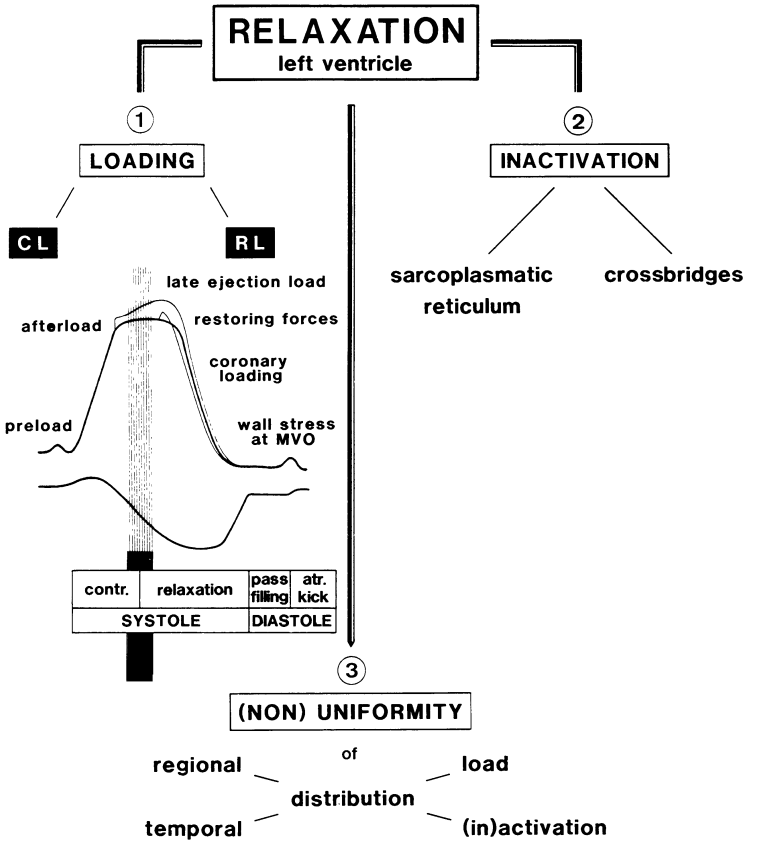

Figure 1. Triple control of relaxation in the human left ventricle.
CL: contraction loading; RL: relaxation loading.
Note the two load clamps, superponed on the pressure tracing: the early clamp (CL) delays pressure fall, where the late clamp (RL) induces an premature onset of pressure fall.

non-uniform distribution of loading conditions and activation front [6–9] (Figure 1).

A.1. Control by load

The primary stimulus for developing hypertrophy both in pathological circumstances and in the athlete's heart is the load to which the muscle in the LV wall is subjected throughout the cardiac cycle. After development of hypertrophy the resulting loading conditions are important determinants of relaxation.

In analysing loading conditions we must consider not only loading levels but also load shifts, or systolic loading profiles. As the real load imposed on the muscle in the LV wall cannot be measured directly, it has been customary to calculate meridional or circumferential wall stress to evaluate it. Wall stress in its simpliest form for a spherical LV (Laplace's law) gives $T = P \times r/2h$ where T = average wall stress; P = transmural pressure, h = wall thickness and r = internal radius. Similarly as in isolated cardiac muscle, the effects on relaxation of early and late systolic loading must be clearly distinguished. This distinction has led to the concepts of contraction loading (CL) and relaxation loading (RL). A load clamp imposed on the LV before or during early ejection (CL) will delay the onset of relaxation: this reflects the ability of muscle fibers to adapt to new loading conditions. The same load clamp imposed during the second half of ejection will have opposite effects and cause a premature onset of relaxation [6, 19, 35] (Figure 1). The onset of relaxation starts when load dependence and the characteristic effects of load alterations (RL) on subsequent pressure fall and LV filling becomes apparent: load dependence requires the presence of calcium sequestering membranes and load will predominate over activation when myoplasmatic calcium has been reduced to sufficiently low levels by the pumping action of these calcium sequestering membranes [8].

Contraction loading is determined by preload and afterload: while *preload* is manifested as the precontraction – or end-diastolic – wall stress, *afterload* (which is determined in a complex way by geometry and dynamics of the left ventricle interacting with aortic impedance) should be measured as wall stress in the first part of ejection, i.e. prior to the transition zone where relaxation loading becomes predominant. Interpretation of afterload indices such as mean ejection stress and end-ejection stress is subject to caution, these indices being measured at least in part during early relaxation. The same criticism should be applied to ejection fraction and pressure-volume relationship as indices of the contraction performance of the LV [8].

Relaxation loading encompasses restoring forces at the level of the cardiac fiber, configurational deformation of the LV, arterial impedance after the transition zone between CL and RL, coronary filling after aortic valve closure and wall stress at (or after) mitral valve opening [6].

The *transition of CL to RL* must be taken into account when the effects on relaxation of pressure or volume loading during ejection are interpreted. Shifts in load from late to early ejection will tend to delay the onset of relaxation, while shifts from early to late ejection will induce premature relaxation. Unaltered relaxation velocity for instance with increase in loading during ejection could result from equal effects on CL and RL simultaneously. Shifts in load can be induced by neurohumoral or pharmacological alterations of arterial impedance, thereby affecting timing and amplitude of reflected waves in late ejection. Moreover, the transition zone may be displaced in some conditions, as e.g. through neurohumoral adjustments and the exact range in time has as yet not been

delineated in the intact heart. This could account for conflicting data resulting from pharmacological interventions. Shifts in the transition zone could also be relevant when comparing acute versus chronic load alterations [8].

Systolic time intervals are helpful in evaluating *timing* of relaxation as a function of loading conditions. For the *rate* of relaxation we must keep in mind the sequence that comprises an isovolumic pressure drop followed by an increase in volume. The isovolumic phase will be evaluated by pressure-derived indices, where peak (–) dP/dt describes an earlier phase than tau (time constant of pressure decay after peak (–) dP/dt); some information about pressure decay can also be derived from intervals, but their interpretation is subject to many pitfalls. The final and perhaps the major hemodynamic event of relaxation, i.e. the rapid filling of the left ventricle, will be measured after mitral valve opening by means of volume-derived indices. An earlier onset of relaxation as following a load clamp in the relaxation phase, does not necessarily imply an accelerated rate of relaxation and the effects on pressure decay have to be differentiated from the effects on LV filling.

A.2. Control by inactivation

Inactivation is mainly determined by the rate and capacity by which intracellular calcium is being pumped by the *sarcoplasmatic reticulum* (SR) and by the detachment rate of actomyosin *crossbridges* which is related to ATP hydrolysis. Both aspects are profoundly influenced by *hypoxia* [12] and can be modulated by biochemical adaptative mechanisms as myosine isoenzyme shifts or changes in the calcium reuptake capacity of the SR.

A.3. Control by non-uniformity

The complex shape of the left ventricle and the complex spreading of electrical depolarization and repolarization makes non-uniformity an obligatory additional determinant of relaxation in the intact heart. This non-uniform activity results in an additional control of energy transfer to haemodynamic activity. Any alteration of this coordinated activity will induce decreased hydrodynamic efficiency and hence contraction and relaxation disturbances [1].

B. Relaxation of the hypertrophied left ventricle

B.1. Pathological hypertrophy: e.g. aortic stenosis

B.1.1. Determinants of relaxation

a. Control by load
– Geometrical adaptation:
Hypertrophy is obtained by enlargement of myocardial cells and hyperplasia of both muscular and non-muscular intra-cellular components. Stimuli which trigger hypertrophy include increased tension generated by the myocardial fibers (afterload), increased end-diastolic wall stress (preload) and neurohumoral factors such as increased catecholamines or discharge of cardiac sympathetic nerves, activation of the renin-angiotensin system and increased levels of thyroxine and growth hormone [36]. In chronic *pressure* overload (e.g. hypertension, aortic stenosis, coarctation) increased systolic wall stress is the primary stimulus that causes parallel addition of new myofibrils, resulting in a ventricle with a normal or even reduced cavity but with a thickened wall [22]. According to Laplace's law the reduced radius-to-wall-thickness ratio normalises wall stress, enabling the left ventricle to eject a normal stroke volume against a high resistance. The desired adaptive response is achieved when the LV functions normally per unit of ventricular mass so that cardiac reserve is reestablished and further overload, as imposed by exercise can be handled normally.

– *Loading conditions* (Figure 2)
– CL: Preload and afterload as estimated from end-diastolic and peak systolic wall stress are either normal or increased. Hence contraction loading will tend to be elevated [17].
– RL: Relaxation loading, as the major driving force for LV filling is profoundly affected. Coronary vessel growth can not keep pace with increased muscle mass. This will result in an impeded filling of the coronary reservoir and hence in the inability of early coronary filling to stretch myocardial fibers as in normal circumstances (Figure 6 in ref. 6). The increased wall thickness with an almost unchanged cavity will severely reduce wall stress at and after mitral valve opening, even in the presence of elevated filling pressures.
– Passive behaviour of the LV in diastole will also be modified: wall stress is reduced by increased wall thickness and the pressure-volume relation will be shifted to the left [24], causing the ventricle to equilibrate at lower mid-diastolic volumes. This modified passive behaviour can explain the lower amplitude of the LV filling during the rapid filling period, and will also partially account for lower peak filling rates: as we know from papillary muscle experiments, peak filling rates are closely related to the extent of filling [20].

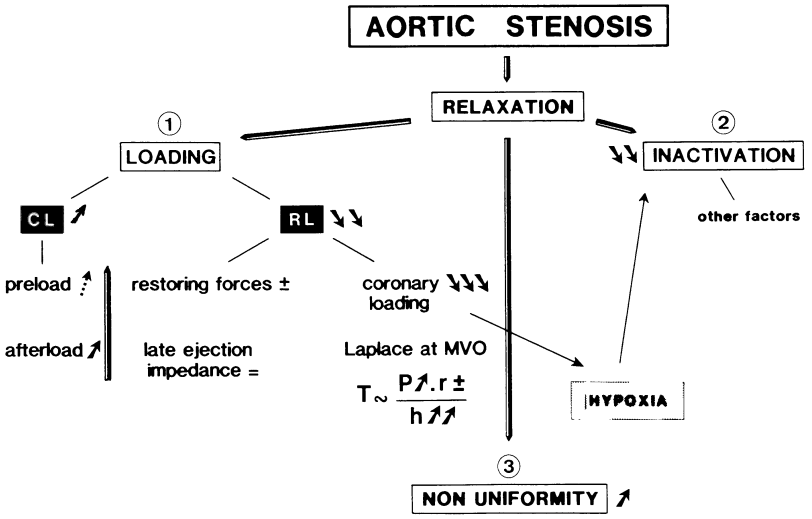

Figure 2. Triple control of relaxation applied to pathological hypertrophy e.g. aortic stenosis.

b. Control by inactivation

– *Contractile proteins:* ATPase activity related to contractile protein (actin and myosin) interaction has been studied in several animal species, but most extensively in the rat [40]. When the heart of an adult rat is subjected to a major *pressure* overload, ATPase activity consistently decreases. When the mechanical overload is removed, ATPase activity recovers. These changes result from isoenzyme shifts from one form of myosin (V1) with a high ATPase activity to another form of myosin (V3) with a lower activity [33, 44].

These findings are not consistently found in *volume* overload: moderate volume overload without increase in systolic wall stress, as induced by aortocaval fistula or atrial septum defect will not result in myosine isoenzyme shifts, in contrast to severe overload with heart failure and in contrast to aortic insufficiency [33].

These data cannot simply be extrapolated to human pathology or athletes: human LV myocardium has both V1 and V3 isoforms but the V1 isoform content is only 6% [34]. Thus there is limited potential for transformation to a greater V3 content with mechanical overload in man.

– *Sarcoplasmatic reticulum:* Hypertrophy due to significant pressure overload has been associated with depressed SR function resulting in a decreased binding or reuptake of calcium [42], hence in a delayed inactivation and in a blunted load dependence [8, 12].

The *mechanical behaviour* of isolated non-hypoxic papillary muscle of the rat is altered as a consequence of these and maybe other mechanisms: contraction

velocity, measured as the maximum velocity of unloaded shortening (V max), is depressed without changes in maximum tension development [3]; relaxation is slowed both in isometric and isotonic contractions but load dependence is preserved [28].

– *Hypoxia:* The coronary circulation in aortic stenosis is characterized by a reduced vasodilator capacity and by a critical blood supply to the subendocardial layers of the myocardium: these findings are linked to ischaemia in several clinical studies [2, 31]. Ischaemia can alter relaxation since for a given set of loadings, relaxation is delayed and slowed by hypoxia and load dependence disappears [12].

c. Control by non-uniformity

Spatial and temporal non-uniformity of loading and inactivation may help to explain impaired relaxation in hypertrophy. Changed geometry, regional variations of wall thickness, interstitial fibrosis, loss of myocardial contractile elements and of normal intercellular connections will undoubtly increase non-uniformity in the hypertrophied ventricular wall. That non-uniformity accompanies impaired relaxation in aortic stenosis is confirmed by echocardiographic studies: the onset of mitral valve opening is delayed with respect to the minimum cavity dimension and significant dimension changes occur in this interval [16, 23]. As these dimension changes occur in the isovolumic relaxation period they cannot be related to volume changes of the LV but are explained by a change in cavity shape, hence by incoordinate relaxation.

B.1.2. Cardiac function and parameters of relaxation

In severe chronic overload, myocardial function eventually fails both during contraction and relaxation, leading to pump failure and extracardial compensation mechanisms. These extracardiac compensation mechanisms will further increase cardiovascular overload, thereby closing the vicious circle of heart failure (Figure 5, left). When an impaired pump function (e.g. decreased ejection fraction) is present in severe aortic stenosis it can be caused by excessive wall stress (inadequately normalized by the hypertrophy), intrinsically depressed contractility or both [10].

Severe relaxation abnormalities are however the hall-mark of concentric hypertrophy and they occur at an earlier stage of the disease than does impairment of contractility [7, 17, 37]. Subnormal LV filling velocities can even precede the development of a pathological increase in LV mass [26]. The filling profile in concentric hypertrophy has a rapid filling phase where both the amplitude of filling and the peak velocity of filling are diminished in comparison to normal subjects [4, 16, 18, 23]. This impaired relaxation is compensated by a vigorous atrial kick that can convey more than 40% of the total filling volume [4, 18] (Figure 3). Accordingly, heart failure in concentric hypertrophy can be merely a problem of relaxation and filling rather than of contraction abnormalities. This

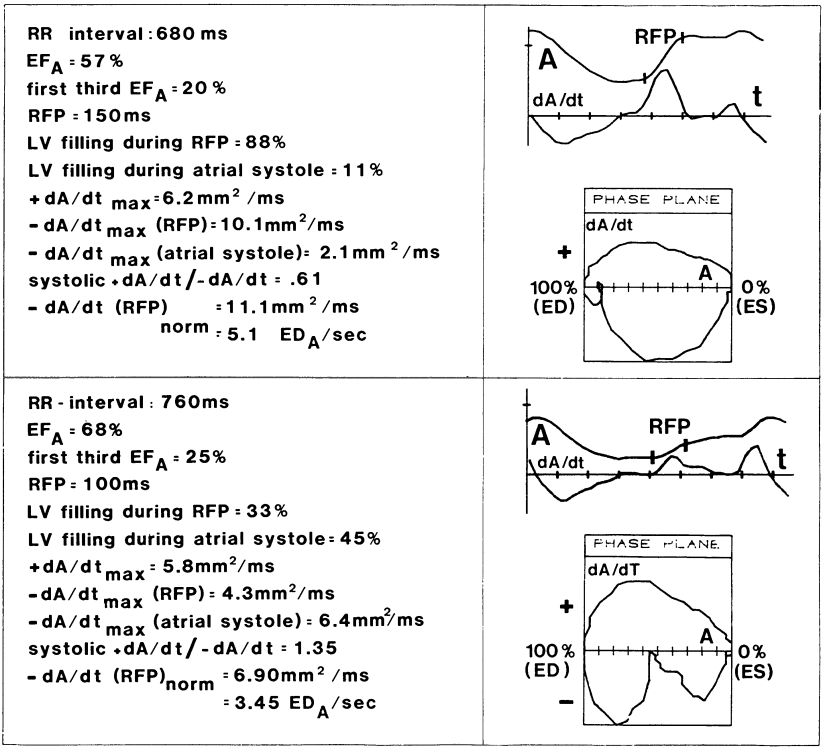

Figure 3. Volume-derived indices of LV function in a normal subject and in a subject with concentric hypertrophy.

2D-echo images are enhanced by averaging 8 cardiac cycles. The averaged cardiac cycle has an increased signal to noise ratio, which allows more accurate endocardial recognition (46). This digitized cardiac cycle is transferred to a computer memory where automatic endocardial edge detection is performed every 20 ms, followed by measurement of various parameters and plotting of a LV area-time and flow-area curve (phase-plane). The phase-plane curve displays the relative area-change (dA-dt) or flow on the vertical axis (contraction above zero) and the relative area (A) on the horizontal axis (100% = largest ventricular volume: 0% = smallest ventricular volume). Note that the curve is independent of absolute magnitude of area and of ejection fraction (EFA). A further normalization is performed to facilitate inter-comparison of flow-area curves so that the peak area-change in the heart cycle occurs at the very bottom or top of the figure. The heart cycle is read clockwise.

The upper panel shows the curves of a normal 24-year old volunteer with a maximal filling rate which is higher than the maximal ejection rate: the ratio of peak +dA/dt on peak −dA/dt is 0.61. A limited LV filling follows atrial contraction. The lower panel shows the curves of a 59-year old female patient with LV hypertrophy due to arterial hypertension. Contraction is vigorous, but both extent and rate of LV filling during rapid filling period are compromized. Striking in the phase-plane curve are the important contribution of atrial systole to LV filling (45%) and the high peak rate of LV filling during atrial systole. This augmented atrial kick results in maintaining pump function during contraction (unchanged EFA and first third EFA) despite a severely impaired relaxation. Modified after Brutsaert DL *et al* [8].

type of failure requires a specific therapeutic approach aimed at enhancing relaxation rather than stimulating contractility.

B.2. The athlete's heart: e.g. cyclists

B.2.1. Determinants of relaxation

a. Control by load

– Geometrical adaptation:

The effects of *endurance training* (dynamic/isotonic training) on LV morphology have been compared to those of sustained chronic volume overload, but in contrast to pathological hypertrophy, cardiac overload in athletes is intermittent. In chronic *volume* overload increased diastolic wall stress will lead to addition of new sarcomeres in series, fiber elongation and LV enlargement. This LV enlargement will lead to increased systolic wall stress even in the presence of an unchanged systolic pressure (Laplace's law), thereby stimulating addition of new myofibrils and secondary wall thickening [22]. The LV has a nearly normal radius-to-wall-thickness ratio and is able to increase stroke volume by the normal function of an increased number of sarcomeres.

Consistent findings in dynamically trained athletes, as opposed to non-athletes, are an increase in LV end-diastolic diameter and a proportional increase in wall thickness [25]. These changes are considered appropriate compensations for the sustained increases in cardiac output during competition and training. In addition heart rate is lowered: this effect has been attributed to an increase in vagal tone and to a decrease in resting sympathetic tone; an intrinsic cardiac component to bradycardia has also been suggested [25]. It remains to be seen to what extent low heart rate in se will perpetuate stimuli for hypertrophy as it is associated with a larger end-diastolic volume and wall stress. In this context, it is well-known that crushing the AV node has been a classical model for experimental hypertrophy in dogs [5].

The effects of *strength training* (static/isometric training) have been compared to those of chronic pressure overload, but for various reasons some disagreement exists concerning the interpretation of the available data. Most studies indicate that weight lifters and wrestlers have normal or increased LV end-diastolic diameter. As these athletes tend to be heavy, the dimensions could be corrected for weight or body surface area: when corrected, standard values are usually obtained. Increase in wall thickness is also present in all strength-trained athletes and the increase in LV mass seems to be related to the level of training. However after correction for lean body mass, athletes do not differ from non-athletic controls in left ventricular mass [25]. As the radius-to-wall thickness ratio is reduced by strength-training [27] and as this cannot be explained by an increase in lean body mass, LV growth has to be considered parallel to muscle growth and

not as the mere consequence of muscle growth.

– *Loading conditions:* (Figure 4)

Loading variations in physiological hypertrophy can be subtle and comparison between athletes and non-athletes is influenced by the various changes that occur, as e.g. the low resting heart rate. Rather than discussing relaxation parameters and loading determinants in general, we reviewed some recent data by Fagard and coworkers [15] who compared cyclists in the competitive season (CS) to the same cyclists in the resting season (RS).

– CL: Preload and afterload are decreased in the CS and increased in the RS, mainly due to a regression of wall thickening in the RS.

– RL: Late ejection impedance, external restoring forces and wall stress after mitral valve opening show some differences that cancel one another and are probably of no significance. In contrast to pathological hypertrophy, several animal studies indicate that training promotes myocardial vascular growth. This increased vascularisation seems proportional to myocardial growth and should be able to normalize oxygen consumption in the hypertrophied myocardial cell [43]. These data suggest the preservation of a normal stretching of the myocardial fibers by early filling of the coronary vascular bed.

– One study analysed passive diastolic behaviour in trained greyhounds: given the LV dilatation, the pressure-volume relation is shifted to the right but despite the increase in mass, LV stiffness was not different from untrained dogs [11].

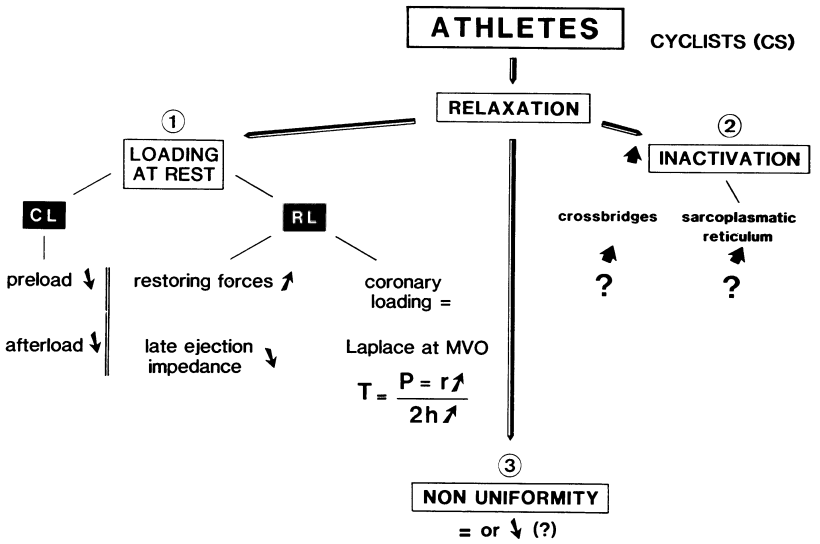

Figure 4. Triple control of relaxation applied to the athlete's heart e.g. cyclists in the competitive season (CS). Data derived from Fagard and coworkers [15].

b. Control by inactivation

– *Contractile proteins:* Physiologic loads such as chronic exercise, which result in marked LV hypertrophy in the rat, may increase contractile performance and myosin ATPase activity as a result of a shift to even a greater predominance of the V1 myosin isoenzyme [39]. Moreover physical training is able to revert a shift to a predominance of V3, induced by hypertension [41]. These data suggest that the effects of hypertension and the effects of physical training are mediated through different mechanisms and that the stimulus induced by repeated swimming can counteract that induced by hypertension.

– *Sarcoplasmatic reticulum:* A possible role for the SR in regulating myocardial intracellular calcium concentrations in trained hearts has been investigated in several rat conditioning models, indicating an enhanced SR activity and an enhanced calcium reuptake [30, 42, 43]. This enhanced SR activity has also been associated with faster relaxation in isolated perfused hearts from swim-trained male and female rats [43]. It is interesting to note that mild pressure overload can result in an increased ATPase activity and in an increased calcium reuptake by SR, findings that are similar to those induced by training [29, 47].

– The *mechanical behaviour* of papillary muscle of trained rats is not impaired as in pathological hypertrophy: several studies show an increase in isometric force development and an increase in shortening velocity. Moreover ventricular relaxation is enhanced in swim-trained rats [43].

– In the presence of a well-adapted coronary circulation [43], *hypoxia* will not occur in contrast to pathological hypertrophy.

c. Control by non-uniformity

Factors contributing to non-uniformity in pathological hypertrophy are among others: configurational changes of the left ventricle, regional changes in wall thickness, gross alterations in cellular morphology, loss of intercellular connections and interstitial fibrosis. These is at present no evidence however that these changes can be induced even by strenuous training.

B.2.2. Cardiac function and parameters of relaxation

In athletes, cardiovascular function is adapted to high performances: training increases maximal cardiac output as evaluated from maximal oxygen consumption ($\dot{V}O_2$ max). Where sedentary middle aged men have a $\dot{V}O_2$ max of 30 ml/kg/min, endurance runners can develop values as high as 85 ml/kg/min. Since heart rate at $\dot{V}O_2$ max is not increased in trained athletes, increased cardiac output is due to increased stroke volume. Increased stroke volume is obtained by geometrical adaptation (increased number of sarcomeres) and by an increased contractility. Moreover a faster relaxation is an additional adaptation to exercise, allowing more complete ventricular filling at rapid heart rates: enhanced relaxation will favour stroke volume and will limit exercise dyspnoea.

The few studies where the rapid filling phase of the cardiac cycle was analysed

at rest consistently indicated normal or slightly supranormal rates of LV filling in competitive swimmers, word-class power lifters [13], ultra-endurance triathletes [14], distance runners [21, 32] and cyclists [15]. The methods used were either M-mode echocardiography [13, 14, 15, 32], radionuclides [21], or Doppler [14]. A single study analysed the rapid filling phase during (moderate) exercise: even when normalized for end-diastolic dimensions, both peak filling rate and early filling volume of the left ventricle were frankly increased in distance runners as compared to non-athletes [32].

A third heart sound is frequently found in endurance-trained athletes. Van de Werf *et al.* [45] showed that the third heart sound is related to deceleration of flow at the end of the rapid filling phase and is associated with a higher and steeper rapid filling wave on the ventricular pressure tracing. A third heart sound occurs either following increased filling rates or when a (sub)normal LV inflow is decelerated by an impaired relaxation. The presence of a third heart sound in athletes is the signature of a high filling rate in the absence of any relaxation disturbances, and can be judged as an index of good training.

C. Conclusion (Figure 5)

Sustained chronic overload of the heart stimulates changes that lead to growth or hypertrophy. This growth is adaptational and tends to neutralize overload. When overload is rapidly evolving or severe, hypertrophy cannot compensate. Moreover hypertrophy is characterized by structural and ultrastructural changes that induce failure of myocardial function, both during contraction and relaxation. Myocardial failure and pump failure will be followed by extracardiac compensation mechanisms that will result in additional overload, closing the vicious circle of heart failure (left circle).

The athlete's heart is a physiological adaptation to intermittent overload that stimulates similar but limited growth. At rest loading levels tend to be low, due to the presence of hypertrophy and due to neurohumoral adaptational mechanisms. Low heart rate will somewhat counteract this underloading at rest. The athlete's heart is characterised by an adapted geometry, an increased contractile performance and also by an increased relaxation capacity, determining the cardiac aspects of increased exercise tolerance induced by training. Why training can promote hypertrophy without dysfunction, in contrast to pathological hypertrophy is still largely unknown, as indicated by the question mark in Figure 5.

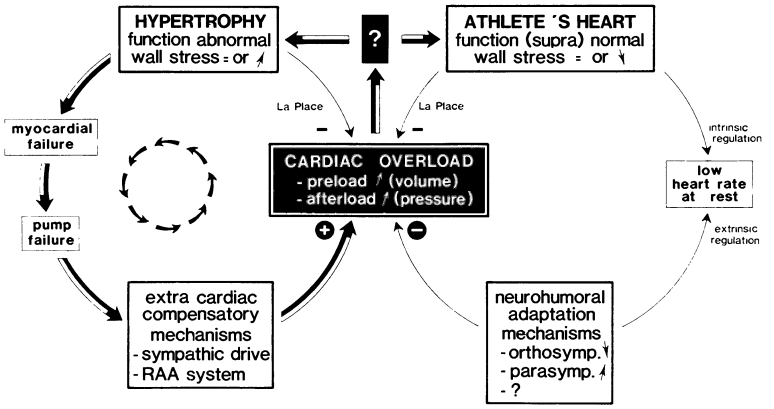

Figure 5. Adaptations to Cardiac Overload (see conclusion).

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Aerobic exercise and cardiac size: an echocardiographic study of Rotterdam marathon runners

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Introduction

Several studies have suggested that endurance exercise such as marathon training leads to left ventricular enlargement. However, the reported increase in dimension as assessed by echocardiography, which is the most accurate method for such an analysis, is rather moderate [1–13, 15, 16]. Moreover, most of these studies include only a small number of athletes compared with non-athletic or even inactive controls. This may introduce some bias as such control groups do not necessarily represent a cross-section of the normal population. In addition, determinants other than training causing differences in cardiac dimensions such as length, weight and heart rate are not always taken into consideration. Recently, regression equations have been evaluated which take these variables into account and therefore allow the calculation of corrected reference values [14]. These equations are based on data collected in 609 normal active subjects. In this study we have studied 52 marathon runners by M-mode echocardiography and compared their cardiac dimensions with those of the controls.

Study group

The marathon runners

During February 1984, we studied 52 runners, who were preparing for the Stad Rotterdam marathon to be held on April 20th, 1984. A large number were members of a local track team. All visited the training sessions regularly and therefore we can say that they participated in a training program which was primarily based on aerobic exercise. None of them had any resting ECG abnormalities, which would have militated against participating in endurance exercise. Most of them had an exercise ECG (ergometry) as part of a medical checkup in the last 6 months. Some of the vital characteristics of the runners are shown in Table 1. One runner presented himself with a tachycardia (125 beats/min) due to overtraining. A few had blood pressure readings which were borderline normal and repeated measurements confirmed this. From the best performance times of previous marathons it is clear that none of them was an elite-class runner, but also that none was a so-called jogger (slowest marathon performance time 3:30).

The reference group and statistical methods

Studies [14] dealing with reference ranges for M-mode echocardiographic measurements have shown the influence of the person's attributes such as weight, height and age on the M-mode measurements. Therefore, when comparing echocardiographic measurements of different patient groups, care must be taken to match the mean values of the attributes of the respective groups.

A statistical model for reference ranges of M-mode echocardiographic measurements has been reported taking into account the person's age, weight, height, sex and RR interval [14]. In this model the estimate M of the measurement is given by the formula:

$$\hat{M} = A \cdot (\text{age})^B \cdot (\text{height})^C \cdot (\text{weight})^D \cdot (\text{RR interval})^E \cdot (\text{sex})^F$$

For every M-mode measurement of a cardiac structure the constant A and the exponents B to F were determined by statistical analysis of measurements taken in 609 normal individuals. The estimate of a specific measurement can be obtained by entering the appropriate values of A to F into the equation. The advantage of the application of this statistical model is that differences in measurements, caused by differences in attributes, are reduced and the remaining variability may be explained by intersubject variability and the variability of the measurement itself. The residual value of the measurements, being the difference between the estimate calculated by the equation, and the actual measurement, is expected to be independent of a person's attributes. In order to compare the

Table 1. Characteristics and performance of 52 marathon runners.

		Mean	Range
Age	(year)	36	22–51
Length	(cm)	178	165–194
Weight	(kg)	70	56–85
Heartrate	(b/min)	85	50–180
Arterial blood pressure			
systolic	(mmHg)	128	100–150
diastolic	(mmHg)	81	65–110
Vital capacity	(l)	5.4	3.1–6.8
Forced expiratory volume (1 sec)	(l)	4.4	2.7–6.1
Peak expiratory force	(l/sec)	10.8	6.3–15.0
Training	(km/week)	85	50–180
Duration	(year)	3	1–20
Marathon time	(h, min)	2:54	2:25–3:20

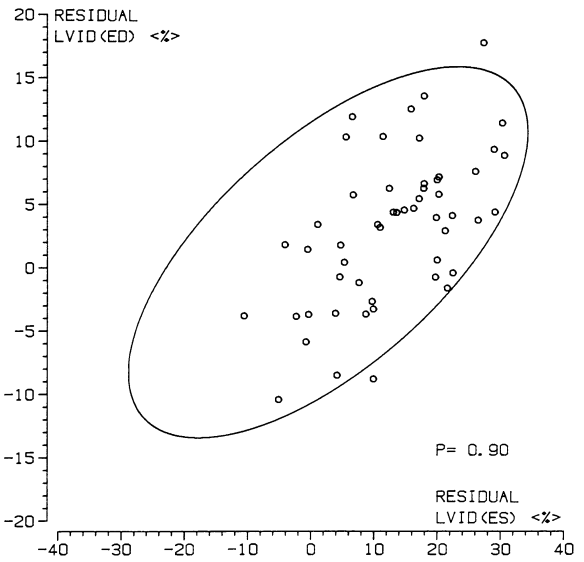

Figure 1. Graph showing the 90% confidence region (ellipse) for the residual values (see text) of end-diastolic and end-systolic left ventricular dimensions in a normal population. The values of each individual marathon runner are represented by open circles. There is no difference between normals and marathon runners.

measurements in a group of patients with the reference ranges of normal individuals one has to compare the means of the residual values in the respective groups using an unpaired t-test. Application of the statistical model provides for more unbiased results in the comparison of measurements in different groups, in cases where the attributes of the individuals of the groups do not match perfectly.

Another application of the model is the definition of reference ranges for a combination of two measurements and the comparison of the same combination of measurements in a different group. In Figure 1 the 90% confidence region has been drawn for the residual values of left ventricular dimension at end-diastole versus end-systole as measured in a group of normal individuals. The squeezed shape of the ellipse represents the fact that the combination of a large end-diastolic dimension of the left ventricle and a small left ventricular dimension at end-systole is unlikely to be found in a normal individual. This fact may be overlooked easily, when the measurements are compared separately.

Results

For reasons of simplicity the thickness of the interventricular septum (IVS) and

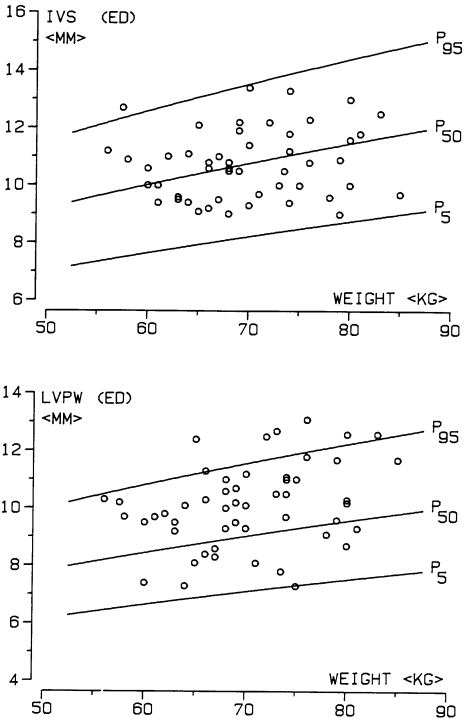

Figure 2. Graph showing the 90% confidence interval (P_5–P_{95}) of interventricular septal (IVS) (upper panel) and left ventricular posterior wall (LVPW) thickness (lower panel) relative to weight derived from a normal population (see text). The individual values of the marathon runners are indicated by open circles.

that of the left ventricular posterior wall (LVPW) of the marathon runners have been plotted as a function of their weight only (Figure 2). The percentile lines in Figure 2 are based on the analysis of 303 normal male subjects weighing 15–120 kg, but only the region between 50 kg and 90 kg is shown here. The data demonstrate that these measurements lay mostly between the 5 and 95 percentile lines of the control group. A similar plot is shown for the end-diastolic and end-systolic left ventricular internal diameter (LVID) (Figure 3). Again the end-diastolic readings are within the normal limits although a larger number of data points are located above the 50th percentile. For the end-systolic value, this is definitely the case. If one calculates end-diastolic and end-systolic volume from these data one will notice that end-diastolic volume is akin, but end-systolic volume larger than that of the control group. Consequently stroke volume is less than normal, and when one combines this finding with the bradycardia, a lower cardiac output is observed.

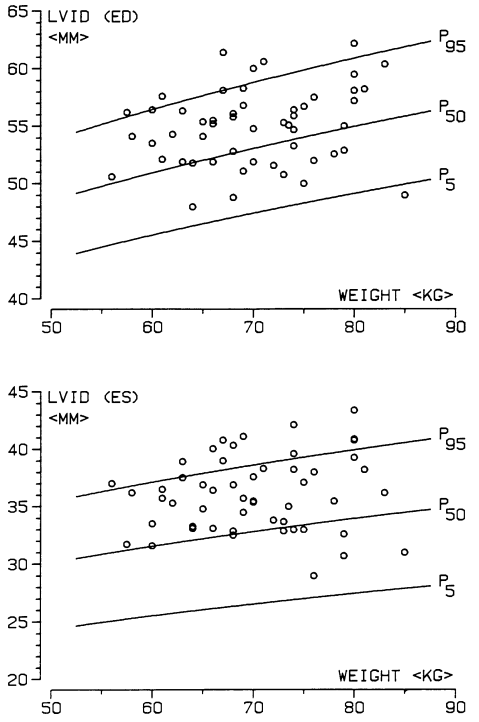

Figure 3. Graph showing the 90% confidence interval (P_5–P_{95}) of the end-diastolic (upper panel) – LVID (ED) – and end-systolic (lower panel) – LVID (ES) – dimensions relative to weight derived from a normal population (see text). Open circles represent individual values of marathon runners.

It must be emphasized that this presentation of the data is very simplistic as it does not correct for heart rate. Corrections for all these factors would bring the characterization of the echocardiographic dimensions of the athletes closer to that of the control group. Figure 1 shows the residual individual values of measurements for end-diastole versus end-systole of the 52 athletes plotted against the 90% confidence region of the controls.

Discussion

Our study represented a well-trained group of athletes following predominantly aerobic training. None of them was a champion runner and there was no reason to suspect them from taking anabolic steroids or stimulants. The left ventricular end-diastolic dimensions were not significantly different from the reference

group but most of them fell above the 50th percentile which may result from an initial selection process. It would be hard to believe that individuals with smaller hearts would persist as long-distance runners. The end-systolic dimensions of the marathon runners clustered between the 50th and 95th percentiles indicating a slightly lower ejection fraction and hence a lower stroke volume. This is at variance with other studies reporting an elevated cardiac output and is most likely the result of a more optimal peripheral oxygen utilization. It is unlikely indeed that a trained heart would work less effectively at rest. Obviously the central and peripheral haemodynamic adjustments resulting from intensive aerobic training such as an increase of central blood volume, a decrease in heart rate, etc. and together, may account for the small increase in cardiac size as observed in most studies.

Another factor is that the lean body mass rather than weight should be considered. In fact, we must accept that for the same weight the dimension would shift to the right and fall within the normal distribution. This shift will not influence the absolute stroke volume. This factor may be a limitation of defining matched controls.

Conclusion

From our results we conclude that a high level of aerobic training does not lead to an increased cardiac size. The fact that they fall above the 50th percentile range may be a result of both a selection process and haemodynamic adjustments. When in addition there is a genetic factor which causes already a large heart above the 95th percentile range prior to the selection process, the haemodynamic adjustments may lead to an enlarged heart. Such a constellation of factors may result in the cardiac performance required to become a top athlete. The proof of this hypothesis will be difficult to obtain as it requires longitudinal rather than cross-sectional studies of athletes and normal subjects. Of course, the effect of anabolic steroids and stimulants so commonly used by the professional and top athletes must also be considered when interpreting such studies.

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The windsurfer's heart

L. MELONI, P. BONOMO and A. CHERCHI

Summary

To assess the adaptive response of the left ventricle (LV) to windsurfing, M-mode echocardiography was performed in 15 male windsurfers, aged 17 to 30 years. Fifteen untrained male subjects, matched for age, height and weight were used as controls.

Athletes showed a significant increase in LV end-diastolic dimension, posterior wall and septal thickness, with a greater estimated LV mass and cross-sectional area. In addition, the ratio of wall thickness to radius was significantly greater in athletes than in controls, suggesting an inappropriate wall thickness.

The present study thus shows that LV hypertrophy occurs in a selected group of windsurfers. The increase in wall thickness appears to be disproportional to LV enlargement, presumably because of a prevalent isometric work component during windsurfing. Finally, our data support the increasing evidence that classification in eccentric or concentric hypertrophy is too restrictive, indicating that a mixed hypertrophy may occur in athletes.

Introduction

Physiological left ventricular (LV) hypertrophy is a well-known adaptive response to exercise in trained athletes [1, 4, 6–10]. Although cardiac adaptation to different types of physical training has been extensively investigated, at present no data is available regarding athletes engaged in windsurfing, a new Olympic sport. The present study was designed for echocardiographic assessment of the morphologic adaptation of the LV in a selected group of windsurfers.

Methods

Fifteen male windsurfers, aged 17 to 30 years (mean age: 23.4 years) were studied. All had been engaged in windsurfing for at least three years. The average training program included 10 hours weekly practice, and at the time of the study, all were at the height of training.

Fifteen males, matched for age, height, weight and body surface area, with no history or clinical findings suggestive of cardiovascular disease served as controls. Although they were not involved in competition sports, all were physically active.

M-mode echocardiograms were obtained with an Organon-Teknika echocardiograph coupled with a Honeywell fiber optic recorder, using a 2.25 MHz transducer, ∅ 12 mm, focused to 7.5 cm, at a chart rate of 50 mm/sec.

Echocardiograms were recorded with the subject in the partial left lateral position by placing the transducer in the standard parasternal position.

The following mean values were determined by averaging at least five cardiac cycles:

- LV end-diastolic dimension (LVIDd), measured at the peak of the R wave of the electrocardiogram from left septal to posterior wall endocardium;
- LV end-systolic dimensions (LVIDs), taken as the smallest vertical distance between left septal and posterior wall endocardium, at end-systole;
- Posterior wall thickness (PWT), measured at end-diastole from the leading edge of the epicardium to the leading edge of the endocardium;
- Interventricular septal thickness (IVST), measured at end-diastole from the leading edge of the right septal echo to the leading edge of the left septal echo;
- LV fractional shortening (FS), calculated as: FS = (LVIDd-LVIDs)/LVIDd %;
- LV relative wall thickness, expressed as end-diastolic thickness/radius ratio: h/R, where R is LVIDd/2 and h is (PWT + IVST)/2 at. end-diastole;
- LV myocardial mass (LVM), calculated as: $LVM = 1.05 \times [(IVST + PWT + LVIDd)^3 - (LVIDd)^3]$;
- Cross-sectional area (CSA) of the LV muscle mass, calculated according to the formula: $CSA = \pi [(LVIDd/2) + Th]^2 - \pi (LVIDd/2)^2$. LVM and CSA were divided by the body surface area.

An unpaired t-test was used to test the significance of differences between the athlete group and controls. All results are expressed as mean ± standard deviation (SD).

Table 1. Clinical data in windsurfers and controls. Values are mean ± SD.

	Windsurfers (N = 15)	Controls (N = 15)
Age (yr)	23.4 ± 4.1	24.4 ± 1.9
Height (cm)	172.4 ± 6.5	171.4 ± 5.3
Weight (kg)	65.0 ± 6.4	65.6 ± 4.1
BSA (m^2)	1.79 ± 0.11	1.79 ± 0.07
HR (b/min)	62.8 ± 4.2	66.3 ± 7.1
SBP (mmHg)	120.4 ± 8.8	121.1 ± 9.2
DBP (mmHg)	69.2 ± 7.9	74.3 ± 6.7

BSA = body surface area; HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure.

Results

Clinical and echocardiographic data are presented in Tables 1, 2 and 3.

LVIDd was significantly greater in athletes (52 ± 3.8 mm) than in the controls (48.5 ± 3.9 mm, $p<0.05$).

LVIDs (32.2 ± 4.2 mm) and FS (37.4 ± 5.5) were not significantly different from control values (30.2 ± 3.4 mm and 37.4 ± 4.1, respectively).

LVPWT and IVST were both significantly increased (9.1 ± 1.1 mm and 11.6 ± 1.4 mm) above normal values (7.5 ± 0.9 mm, $p<0.001$ and 9.0 ± 1.2 mm, $p<0.001$, respectively).

Thickness/radius ratio was significantly higher in athletes (0.40 ± 0.05) than in the controls (0.33 ± 0.03, $p<0.001$).

Estimated LV mass (143.9 ± 23.6 g/m^2) and CSA (11.5 ± 1.4 cm^2/m^2) were both increased above the normal valves (95.9 ± 22.2 g/m^2, $p<0.001$ and 8.3 ± 1.5 cm^2/m^2, $p<0.001$, respectively).

Table 2. Left ventricular echocardiographic data in windsurfers.

Case (no.)	LVIDd (mm)	LVIDs (mm)	FS (%)	PWT (mm)	IVST (mm)	Mass (g/m^2)	CSA (cm^2/m^2)	h/R
1	59.6	39.1	34	10.2	10.9	164.8	12.9	0.38
2	51.0	28.6	44	10.0	14.7	162.1	12.5	0.48
3	54.8	31.1	43	10.0	13.0	123.3	10.5	0.44
4	47.3	33.8	28	8.6	12.3	178.6	13.3	0.42
5	47.5	30.8	35	10.1	11.1	126.6	10.7	0.44
6	52.0	30.6	41	10.0	11.3	168.3	13.2	0.40
7	51.3	34.2	32	9.3	11.0	130.3	10.5	0.39
8	52.5	33.2	36	8.2	10.6	126.3	10.1	0.35
9	53.6	31.1	42	7.3	9.4	123.1	9.8	0.31
10	54.0	30.3	43	6.8	10.3	126.2	10.1	0.32
11	49.6	31.4	36	7.9	13.4	127.5	10.4	0.43
12	59.6	44.0	26	9.0	11.0	180.7	12.9	0.33
13	49.0	29.0	40	9.4	10.0	119.4	10.0	0.39
14	47.3	28.1	39	9.3	12.6	129.4	11.9	0.49
15	51.0	29.0	43	10.3	13.1	172.4	13.4	0.45
Mean	52.0	32.2	37.4	9.1	11.6	143.9	11.5	0.40
SD	3.8	4.2	5.5	1.1	1.4	23.6	1.4	0.05

LVIDd = end-diastolic left ventricular dimension; LVIDs = end-systolic left ventricular dimension; FS = fractional shortening; PWT = posterior wall thickness; IVST = interventricular septal thickness; Mass = left ventricular mass; CSA = cross-sectional area; h/R = end-diastolic wall thickness/radius ratio.

Discussion

Cardiac adaptation in trained athletes has been extensively investigated by means of echocardiography. It is generally believed that two different types of LV hypertrophy develop as the result of different types of physical training: athletes who perform dynamic exercise, such as long-distance runners, show left ventricular enlargement with a proportional increase in wall thickness (eccentric hypertrophy), whereas the increase of wall thickness with a normal-sized left ventricle (concentric hypertrophy) is found in strength athletes such as weight lifters, wrestlers and throwers [7, 8]. Nevertheless, this classification is subject to controversy, and while there is general agreement about the presence of eccentric hypertrophy in endurance athletes [4, 6–10], reports on LV adaptation to strength training are less consistent. Concentric hypertrophy in strength athletes was initially emphasized by some authors [7], but others failed to show any change in LV cavity and wall thickness compared to endurance athletes after normalization of values for body surface area [9].

Furthermore, it is apparent that the classification of hypertrophy as eccentric or concentric which is derived from physiopathologic concepts [5], is not easily employable since athletes rarely perform exclusively isotonic or isometric exercise [1, 3]. A mixed eccentric-concentric hypertrophy has recently been described in cyclists, in whom isotonic exercise is combined with isometric work of the arms [1].

Windsurfing is a special situation with a predominantly isometric muscular strain required during races lasting at least 40 minutes.

The present study provides an M-mode echocardiographic demonstration that left ventricular hypertrophy develops as an adaptive mechanism in a selected group of windsurfers. Calculated LV mass and cross sectional area were significantly larger in athletes than in controls in relation to both LV end-diastolic

Table 3. Left ventricular echocardiographic data in windsurfers and controls. Values are mean ± SD.

	Windsurfers (N = 15)	Controls (N = 15)
LVIDd (mm)	52.0 ± 3.8*	48.5 ± 3.9
LVIDs (mm)	32.2 ± 4.2	30.2 ± 3.4
FS (%)	37.4 ± 5.5	37.4 ± 4.1
IVST (mm)	11.6 ± 1.4**	9.0 ± 1.1
PWT (mm)	9.1 ± 1.1**	7.5 ± 0.9
Mass (g)	257.7 ± 44.2**	171.7 ± 38.2
Mass (g/m^2)	143.9 ± 23.6**	95.9 ± 22.2
CSA (cm^2)	20.6 ± 2.9**	14.8 ± 2.4
CSA (cm^2/m^2)	11.5 ± 1.4**	8.3 ± 1.5
h/R	0.40 ± 0.05**	0.33 ± 0.03

* $p<0.05$, ** $p<0.001$ vs. controls. Abbreviations are as in Table 2.

enlargement and wall thickness increase, with no significant change in LV fractional shortening.

Furthermore, we calculated the h/R ratio [2], an index of LV hypertrophy that reflects the mutual adaptation between wall thickness and ventricular dimension, in an attempt to identify the type of LV hypertrophy. This ratio was found significantly greater in windsurfers than in controls, resulting in an inappropriate wall thickness and suggesting a predominant pressure overload during windsurfing.

Thus, as the increased LV end-diastolic dimension was associated with a disproportional increase in wall thickness, a mixed type of LV hypertrophy was apparent.

In conclusion, adaptive cardiac changes in windsurfers are characterized by an increase in LV wall thickness and end-diastolic dimension. Increase in wall thickness appears to be disproportional to LV enlargement, presumably because of the prevalent isometric work component during windsurfing. Finally, our data support the increasing evidence that classification in eccentric or concentric hypertrophy is too restrictive, indicating that a mixed LV hypertrophy may occur in athletes.

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An investigation of athlete's heart by chest X-ray, electrocardiography and echocardiography

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Summary

The heart of 184 athletes, involved in different types of sports, were studied by chest X-ray, electrocardiography and echocardiography. Highly significant correlations were found between the radiologic heart volume and echocardiographic dimensions. However, the electrocardiographic parameters correlated poorly with heart volume and with the echocardiographic data. Therefore the degree of physiological cardiac hypertrophy in athletes cannot be evaluated by ECG. Furthermore, no clear differences could be demonstrated by echocardiography between endurance- and strength-trained athletes.

Introduction

Besides the two usual non-invasive methods to evaluate athlete's heart – chest X-ray and electrocardiography – echocardiography has been introduced in sport medicine [7]. As there are many studies on the relationships between the results from X-ray and ECG [2, 5, 9] and only a few comparisons between X-ray and echocardiographic data [3, 8], a detailed comparisons of the three methods was undertaken.

Methods

The investigations were performed in 184 athletes, 66 females and 118 males. They were involved in different kinds of sports and all were members of German national teams. The X-ray heart volume (HV) has been measured by the usual biplane radiological method. ECG indices of Sokolow-Lyon were calculated for the estimation of right ventricular hypertrophy ($RV_1 + SV_5$), and of left ventricular enlargement ($SV_1 + RV_5$). M-mode echocardiography was used to determine the left ventricular internal diameter (LVID), the septal (IVST) and the posterior wall thickness (LVPWT), and the sum of these measurements, i.e. left ventricular total diameter (LVTD); only results at end-diastole are reported. Lean body mass was determined by a caliper method [1].

Results and discussion

The absolute radiological heart volumes and HV corrected for body weight are summarized in Table 1, both for men and for women, involved in different kinds of sports. The indices of Sokolow-Lyon, for both sexes, are listed in Table 2, and

Table 1. Absolute heart volume (HV) and heart volume corrected for body weight (HV/kg) in men and women involved in different kinds of sports. Values are means ± standard deviation.

			Control group	Canoe	Games	Swimming	Long-distance running	Cycling	Rowing	Strength-training
Men	HV	$\bar{x}$	696	943	923	860	971	1012	1131	999
	(ml)	s	95	61	152	214	163	158	135	103
	HV/kg	$\bar{x}$	10.40	13.39	12.29	14.12	14.08	14.63	12.88	10.30
	(ml/kg)	s	1.66	1.63	1.38	1.97	1.97	2.37	0.80	1.24
Women	HV	$\bar{x}$	619	623	547	697	686			
	(ml)	s	117	106	74	122	106			
	HV/kg	$\bar{x}$	10.39	10.47	11.15	12.05	12.90			
	(ml/kg)	s	1.15	1.23	1.29	1.69	1.41			

Table 2. Indices of Sokolow and Lyon, $RV_5 + SV_1$ for left ventricular hypertrophy and $RV_1 \pm SV_5$ for right ventricular hypertrophy, in men and women involved in different kinds of sports. Values are means ± standard deviation.

			Control group	Canoe	Games	Swimming	Long-distance running	Cycling	Rowing	Strength-training
Men	$RV_5 + SV_1$	$\bar{x}$	2.75	2.92	3.70	3.06	3.28	3.66	3.19	3.21
	(mV)	s	0.86	0.54	1.30	0.71	1.22	1.00	0.64	0.92
	$RV_1 + SV_5$	$\bar{x}$	0.49	0.64	0.67	0.66	0.68	0.80	0.55	0.62
	(mV)	s	0.28	0.13	0.32	0.30	0.31	0.32	0.32	0.26
Women	$RV_5 + SV_1$	$\bar{x}$	2.01	1.81	2.35	2.25	2.54			
	(mV)	s	0.70	0.51	0.78	0.70	0.85			
	$RV_1 + SV_5$	$\bar{x}$	0.31	0.31	0.44	0.37	0.42			
	(mV)	s	0.11	0.10	0.19	0.16	0.20			

the echocardiographic parameters of the male athletes are shown in Table 3. We found an enlargement of the left ventricular internal diameter and of the septal and LV posterior wall thickness, and also of heart volume, both absolutely and when related to body weight, in typically endurance-trained athletes such as cyclists and long-distance runners. These results are to be considered as a consequence of the training. Entirely similar adjustments were found in strength-trained athletes but only for the absolute values of heart volume, not after correction for body weight. The cardiac enlargement in strength-trained athletes is regarded as a consequence of the increased body mass.

Therefore we could not confirm the findings of Morganroth *et al.* [6], who considered the cardiac hypertrophy of endurance-trained athletes as only dilatation and of strength-trained athletes as pure concentric hypertrophy. Similarly we could not find a predominant thickening of the septum in power-trained athletes, as was described by Dickhuth *et al.* [4].

Furthermore we performed regression analysis (Pearson) to compare the results from chest X-ray, echocardiography and electrocardiography. As shown in Table 4, highly significant correlations were found between the radiological heart volume, and respectively the echocardiographic left ventricular internal diameter and the total diameter, both for men and for women. Taking both sexes together the correlation coefficients were 0.75 for LVIDd and 0.81 for LVTDd. The r values were lower but still significant for the LV posterior wall thickness.

On the other hand the correlations between the electrocardiographic Sokolow-

Table 3. Left ventricular internal diameter (LVID), left ventricular posterior wall thickness (LVPWT), interventricular septal thickness (IVST) and LV total diameter (LVTD) in male athletes. Values are means ± standard deviation.

		Control group	Canoe	Games	Swimming	Long-distance running	Cycling	Rowing	Strength-training
LVID									
(cm)	$\bar{x}$	4.83	5.39	5.48	5.19	5.59	5.71	5.96	5.83
	s	0.36	0.26	0.45	0.67	0.41	0.40	0.30	0.27
LVPWT									
(cm)	$\bar{x}$	0.93	1.00	1.10	0.98	1.02	1.15	1.10	1.05
	s	0.11	0.09	0.13	0.16	0.10	0.10	0.08	0.10
IVST									
(cm)	$\bar{x}$	0.93	1.06	1.08	1.03	1.02	1.12	1.14	1.12
	s	0.12	0.11	0.15	0.15	0.10	0.18	0.12	0.14
LVTD									
(cm)	$\bar{x}$	6.69	7.45	7.66	7.21	7.63	7.97	8.21	8.00
	s	0.43	0.33	0.61	0.87	0.48	0.55	0.41	0.34

Lyon index for left ventricular hypertrophy and radiological heart volume were of borderline significance for the sexes separately and the correlation coefficient was only 0.45, though highly significant ($P \leq 0.001$), when both sexes were considered together. These rather low correlations can be explained by factors, such as differences in body mass and fat content. Similarly we found poor correlations between the echo- and electrocardiographic variables. The relation between the Sokolow-Lyon index and the left ventricular total diameter, given in Table 5, is only 0.41 ($P \leq 0.001$) for the two sexes combined, and is even not significant in the women.

In conclusion, when one considers the three most important non-invasive techniques to study athlete's heart, the degree of physiological cardiac hypertrophy cannot be evaluated by ECG. In contrast there are highly significant correla-

Table 4. Results of regression analysis relatingheart volume (HV) to left ventricular internal diameter (LVID), LV posterior wall thickness (LVPWT) and LV total diameter (LVTD), for men and women separately and combined.

Parameter		Regression equation	r	p
y: HV	♂	$y = 245.0 \times - 399.1$	.70	≤.001
x: LVID	♀	$y = 117.7 \times + 81.9$	.58	≤.001
	♂♀	$y = 284.7 \times - 662.6$	.75	≤.001
y: HV	♂	$y = 661.9 \times + 262.0$	.53	≤.001
x: LVPWT	♀	$y = 164.1 \times + 517.3$	.26	.036
	♂♀	$y = 865.9 \times - 9.4$	.64	≤.001
y: HV	♂	$y = 189.5 \times - 491.8$	.75	≤.001
x: LVTD	♀	$y = 101.1 \times - 18.7$	.60	≤.001
	♂♀	$y = 220.3 \times - 761.3$	.81	≤.001

Table 5. Results of regression analysis relating $RV_5 + SV_1$ to heart volume, left ventricular internal diameter (LVID) and LV total diameter (LVTD).

Parameter		Regression equation	r	p
y: $RV_5 + SV_1$	♂	$y = 0.0009 \times + 2.49$	.20	.033
x: HV	♀	$y = 0.0011 \times + 1.40$	.24	.053
	♂♀	$y = 0.0024 \times + 0.90$	.45	≤.001
y: $RV_5 + SV_1$	♂	$y = .4181 \times + 1.026$	.24	.008
x: LVID	♀	$y = -.5175 \times + 4.708$	−.10	.411
	♂♀	$y = .6448 \times - .514$	.35	≤.001
y: $RV_5 + SV_1$	♂	$y = .3687 \times + .520$	.27	.003
x: LVTD	♀	$y = -.2911 \times + 4.112$	−.06	.651
	♂♀	$y = .5784 \times - 1.326$	.41	≤.001

tions between radiologic and echocardiographic data. An advantage of the radiological evaluation of heart volume is that it is three-dimensional, with a smaller miscalculation in comparison to the one-dimensional M-mode echocardiographic technique. Advantages of the echocardiographic evaluation are the absence of the X-ray load as well as the possibility to differentiate between dilatation and hypertrophy. In our hands the latter technique does not show a different adjustment of the heart, i.e. left ventricular hypertrophy or dilatation, in response to different kinds of sports.

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§3. RADIONUCLIDE SCINTIGRAPHY IN ATHLETES

Value of radionuclide angiography at rest and during exercise in the assessment of cardiac function in athletes

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Summary

The cardiac function of athletes and untrained subjects differs at rest and during exercise. The assessment of differences between the two groups and the evaluation of progressive cardiac changes in individuals subjected to physical training represents a fascinating but difficult enterprise, mainly because of limitations in the reproducibility of results during exercise. Among the non-invasive techniques, radionuclide angiography provides most reproducible data and allows investigation of changes in end-diastolic and end-systolic volumes, stroke volume, ejection fraction, cardiac output, ejection rate and diastolic filling rates.

Rerych *et al.* [16] have studied the effect of conditioning in 18 athletes. At maximal exercise, cardiac output was higher after training due to a 19% increase in end-diastolic volume; the heart rate and left ventricular ejection fraction remained constant. In these athletes, the LV ejection fraction rose by 22% from rest to maximal exercise due to increased end-diastolic and decreased end-systolic volumes. By contrast, post-myocardial infarction patients differed from athletes by an exercise-induced increase in end-systolic volume [6].

Further studies using gated equilibrium or single-pass radionuclide angiography in athletes are needed to evaluate changes in cardiac function related to the variety of training programs available.

Introduction

Physical training of athletes causes adaptation of the cardiovascular system, the skeletal musculature and respiratory function. Among these adaptations, the assessment of changes in cardiac function during exercise represents a fascinating but difficult enterprise: invasive methods such as catheterization are difficult to use during exercise and are not likely to be repeated; non-invasive methods are limited either by technical aspects of data acquisition or by the approximations used in the expression of results. Among non-invasive techniques, echocardiography and radionuclide cineangiography have been chosen by the majority of workers. Echocardiography has the advantage of investigating regional function by measuring the thickness of the myocardial walls in end-diastole and end-

systole [5, 7, 20]. Unfortunately, this measurement requires precise definition of wall structure which may not be possible, for instance due to chest configuration. In addition, the reproducibility of measurements taken during exercise is poor.

On the other hand, acquisition of data with radionuclide cineangiography is barely affected by chest anatomy. This technique relies on the proportionality between radioactivity counts and ventricular volumes in selected regions of interest. As demonstrated by several investigators [9, 12, 15, 18, 22, 24] reproducibility of results with radionuclide angiography is better than with echocardiography. Repeated studies can be performed at rest, during several intensities of exercise and during recovery.

Methods

In the equilibrium technique, erythrocytes are labeled with technetium 99 m (half-life: 6 hours; peak energy: 140 Kev); various labeling modalities can be used: in vivo, in vitro or semi in vivo-in vitro. We used the in vivo technique with administration of stannous chloride (0.03 ml/kg) followed 20 min later by injection of 25 mCi technetium 99m. Using this method, the required labelling stability can be obtained for several hours. Data are collected in a 35-degree left anterior oblique projection with a 10-degree cranio-caudal angulation of the camera, at rest, during exercise (with a 3-min stepwise increase in intensity) and during recovery. Acquisition takes place during the last 2 min of each stage. End-diastolic and end-systolic volumes, stroke volume, ejection fraction and cardiac output are routinely evaluated. Filling and ejection rates can also be calculated from the ventricular volume curves. The ratio of left to right ventricular stroke volumes is commonly used to evaluate cardiac shunts or valvular regurgitation. Phase images are recorded to investigate conduction abnormalities such as bundle-branch block or Wolff-Parkinson-White syndrome, and to evaluate the regional sequence of contraction and the effects of asynergy.

In the single-pass technique, the need for repeated studies at rest, during exercise and after recovery requires several bolus injections of ultra-short lived isotopes. Among those available, iridium-191m produced from the osmium-191-iridium-191m generator probably has the most advantageous physical characteristics [13]. By comparison with the gated equilibrium technique, the single-pass technique [12] requires collection of a larger number of counts over a shorter period of time. This has most frequently been performed with multicrystal cameras, however these imaging devices have inferior energy discrimination and poorer spatial resolution than single-crystal cameras.

Results

Most workers [3, 8, 10, 11, 14, 17, 23] have used radionuclide cineangiography for the diagnosis of coronary artery disease. The evaluation of wall motion abnormalities, especially during exercise, has improved the selection of patients for physical training. Some authors [4, 6, 21, 23] have studied cardiac function in ischaemic patients (especially left ventricular ejection fraction) before and after physical training, without finding a significant effect of training on cardiac parameters. On the other hand, the number of radionuclide studies in athletes is limited [1, 16].

Rerych *et al.* [16] studied 18 normal athletes before and after a six-month period of intensive training for competition swimming (group selected at random from the North Carolina State University Swimming Team). This team was comprised of 12 males and 6 females, with a mean age of 19 years. Data were recorded with a multicrystal gamma camera. The detector of the instrument was positioned directly anterior to the precordium with the subject sitting erect on a bicycle ergometer.

Results are summarized in Table 1. The mean heart rates achieved at the end of exercise were 185 ± 10 SD and 181 ± 4 beats/min, respectively before and after training, i.e. 91% of the maximal predicted heart rate. At the end of the training program from rest to maximal exercise Rerych *et al.* [16] observed an 18% increase in end-diastolic volume and a 56% decrease in end-systolic volume, leading to a 35% increase in stroke volume and a 22% increase in the left ventricular ejection fraction. The mean effect of training was a significant increase in end-diastolic volume, both at rest and during exercise, along with an increase in stroke volume in both conditions leading to an increase in cardiac output, significant only during exercise (from 22.5 ± 5.7 to 32.1 ± 8.7 l/min). The

Table 1. Cardiac function at rest and during maximal exercise in the sitting position on a bicycle ergometer (from Rerych *et al.*, 1980 [16])

	Before training		After training	
	Rest	Exercise	Rest	Exercise
Hearts rate (beats/min)	74 ± 11	185 ± 10	61 ± 7	181 ± 4
Mean blood pressure (mmHg)	93 ± 8	114 ± 7	83 ± 6	104 ± 8
Cardiac output (l/min)	6.9 ± 1.1	25.5 ± 5.7	6.7 ± 1.1	32.1 ± 8.7
L.V. ejection fraction (%)	73 ± 6	87 ± 4	67 ± 4	86 ± 5
End-diastolic volume (ml)	133 ± 35	167 ± 40	167 ± 40	204 ± 39
End-systolic volume (ml)	38 ± 16	22 ± 7	57 ± 21	25 ± 10
Stroke volume (ml)	98 ± 22	146 ± 28	112 ± 26	172 ± 43

(Values are means ± SD)

greatest cardiac output was reached at extreme exertion by an Olympic silver medalist: 56.6 l/min. The mean ejection fraction decreased at rest from the beginning to the end of the training program (73 ± 6 to 67 ± 7% $p = 0.0006$) but there was no significant change in the mean ejection fraction during maximal exercise. The total blood volume was also shown to be higher after training.

In summary, these data show the haemodynamic importance of the increase in end-diastolic volume measured at rest and during maximal exercise, after training. This adaptation appears to be the primary mechanism for the observed increase in cardiac output during maximal exercise after training in athletes studied in the sitting position.

Bar-Shlomo *et al.* [1] compared 18 normal sedentary controls and 9 endurance-trained athletes (7 males and 2 females; mean age: 19 years). Each athlete had been in intensive training for at least 3 years before the investigation. Unlike the previous report, subjects were studied in the supine position using a bicycle ergometer. The study primarily considered changes from rest to exercise in athletes and normal untrained subjects. Athletes achieved a mean maximal heart rate of 175 ± 11 beats/min whereas control subjects reached 154 ± 19 beats/min. From rest to exercise, the left ventricular (LV) ejection fraction (EF) increased significantly, as shown in Table 2; nevertheless, there was only a slight and non-significant rise in the EF of athletes by comparison with controls. Bar-Shlomo *et al.* [1] did not consider end-diastolic volumes in absolute terms, but rather, chose to compare changes between complete rest and exercise. During exercise they found a significant 24% increase in end-diastolic volume in normals, whereas there was no significant change in athletes. Both groups showed a significant decrease in end-systolic volume from rest to exercise, respectively 36% in athletes and 19% in controls. The authors concluded that athletes differ from normals by a more complete emptying of their ventricles at end-systole and by the absence of end-diastolic volume increase during peak exercise.

Table 2. Cardiac function at rest and during peak exercise in athletes and control subjects (from Bar-Shlomo *et al.*, 1982 [1]).

	Control subjects		Athletes	
	Rest	Exercise	Rest	Exercise
Heart rate (beats/min)	70 ± 10	154 ± 19	65 ± 11	175 ± 11
Mean systolic blood pressure (mm Hg)	122 ± 15	192 ± 34	113 ± 13	205 ± 22
LV ejection fraction (%)	65 ± 6	77 ± 8	65 ± 10	80 ± 6
End-diastolic volume (%)	100	124 ± 9	100	NS
End-systolic volume (%)	100	81 ± 7	100	64 ± 15

(Values are means ± SD)

Discussion

While the results of Rerych *et al.* [16] and Bar-Shlomo *et al.* [1] may initially appear contradictory, differences between the two studies could be partially accounted for by differences in the position of the subjects during exercise and long-term versus acute modalities of the studies.

Athletes, untrained normal subjects and coronary patients appear to have different patterns of adaptation to exercise. Moreover, in a given group of post-myocardial infarction patients, differences can be seen depending on the functional importance and sometimes the location of the infarction [6]. Therefore, a great disparity is observed between the different groups of subjects studied at rest and during exercise. To facilitate comparison of studies by different laboratories there is a need for uniform investigation techniques to be adopted. Exercise in the sitting position is closer to real-life situations, and the choice between equilibrium and single-pass techniques will depend on local facilities. Further studies are needed, for instance in different groups of athletes, in order to more precisely evaluate the differences in cardiac adaptation between individuals participating in a variety of training programs.

Further studies could also be carried out to analyse possible changes in left ventricular filling patterns associated with training and resultant cardiac hypertrophy. Radionuclide angiography could be a useful tool for such studies. Recently, Spirito *et al.* [19] have compared the evaluation of diastolic function by a Doppler echocardiographic technique and by radionuclide angiography; they investigated early and late diastole, showing a good concordance between flow-velocity decay time and isovolumic relaxation time along with flow velocity decay time and the measurement of the rapid filling phase for the estimation of early diastolic indices. For the study of late diastole, the authors again found a good correlation between the integral of the flow-velocity peak due to atrial contraction and the percentage of left ventricular filling during atrial systole, estimated from radionuclide angiographic measures.

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Abnormal electrocardiographic exercise test in middle-aged athletes: correlation with exercise myocardial perfusion scintigraphy

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Summary

Use of exercise testing in the field of sports medicine for fitness evaluation, may disclose ischaemic responses to exercise. In such cases difficult problems of clinical clarification arise and further tests are required owing to the poor predictive value of exercise testing in asymptomatic subjects.

An exercise thallium-201 myocardial scintigraphy was thus performed in 16 sportsmen, aged 27–54 years, who exhibited a positive exercise test during a cardiological fitness evaluation. Eleven patients had a normal scan and 5 a reversible perfusion defect; in one case a non-reversible defect was also evident. Of these 5 patients, a high probability of coronary artery disease was found in 3 cases, while an early congestive cardiomyopathy was detected in 2 young subjects by means of echocardiography and exercise radionuclide angiocardiography.

Our data demonstrate the value of exercise thallium-201 myocardial scintigraphy to clarify the meaning of a positive exercise test in asymptomatic subjects evaluated for cardiological fitness for sport activity.

Introduction

Electrocardiographic abnormalities in athletes pose a diagnostic challenge to the cardiologist and medico-legal problems of clarification may also arise [10]. The most common electrocardiographic findings are sinus bradycardia, increased QRS amplitude, atrioventricular and right intraventricular conduction defects, and ventricular repolarization abnormalities [5]. Ventricular repolarization abnormalities are usually pseudo-ischaemic and several etiopathogenetic hypotheses have been proposed to account for the high incidence of such abnormalities in athletes [9].

Exercise testing is the most important preliminary diagnostic study for the evaluation of ventricular repolarization abnormalities; the normalization of ST-T wave abnormalities during exercise is generally considered to indicate benign disorders. Conversely, the persistence of ST-T abnormalities during exercise testing or their onset in subjects with a normal resting ECG pose problems in interpretation and must be clarified by further investigations.

Ischaemic ventricular repolarization abnormalities rarely occur in athletes during exercise testing. Nevertheless, the increasing frequency of sport activity among older subjects has led to an increased incidence of positive exercise tests in asymptomatic sportsmen. Owing to the poor predictive value of exercise testing in such patient groups, presenting a low prevalence of coronary artery disease, many tests have been proposed to separate true-positive from false-positive responses: hyperventilation, potassium, pharmacological tests with beta-blockers, atropine, isoproterenol and dopamine [11]. The diagnostic reliability of these tests is still controversial.

In recent years a significant improvement in the clarification of the electrocardiographic responses to exercise has been offered by exercise myocardial perfusion scintigraphy with thallium-201. The technique has proved to be more sensitive and more specific than its electrocardiographic counterpart [2–4, 7]. A thallium-201 perfusion defect appearing during exercise and reversing after 4 hours suggests an area of transient myocardial ischaemia.

This study was undertaken to assess the diagnostic value of exercise thallium scintigraphy in subjects who exhibited a positive exercise test at a cardiological fitness evaluation.

Methods

The study included 16 male subjects aged 25–54 years (mean age 37.6 years) practising competitive sports. Nine subjects had no coronary risk factors, while only one risk factor was present in 7 (smoking of more than 10 cigarettes per day in 6 and mild arterial hypertension in 1). The resting ECG was normal in 7 cases, with ventricular repolarization abnormalities present in the remaining 9. Resting 12-lead electrocardiograms were recorded in the lying and standing position and during 60 sec of hyperventilation. A maximal exercise test was performed on a motorized treadmill, according to the Bruce protocol, while the ECG was continuously monitored and recorded with a multichannel system (Exer Stress Avionics Model 3000). The CM lead system was used to record the precordial leads. Complete ECG and blood pressure were recorded at 1 min intervals during exercise and recovery. The criterion for a positive exercise test was an ST segment depression of at least 1.5 mm, measured at 0.08 sec from the J point. In all cases also M-mode and two-dimensional echocardiography was performed using an ATL MK 300 IC system according to standard techniques.

All patients underwent exercise thallium-201 myocardial scintigraphy within 1 month of the exercise test. Exercise was performed in the supine position by means of a variable-load bicycle. Upon development of an ST segment depression of at least 1.5 mm, 2 mCi of thallium-201 were injected into an antecubital vein and the patient was then requested to continue exercise for 60 to 90 sec more. Each patient underwent imaging in the supine position under a Pho Gamma V

scintillation camera, 2 to 5 min after thallium injection; in case of perfusion defects, a redistribution scan was performed 4 hours later.

Using a medium-sensitivity, parallel-hole collimator, we obtained images in the following sequences: 45° and 60° left anterior oblique, anterior and left lateral projections, collecting a total of 500 K counts per image. Images were stored in a computer (Digital Equipment Co PDP 11/34) for subsequent image processing and semi-quantitative analysis, performed by interpolative background subtraction, according to Goris, and for elaboration of circumferential profiles. All studies were interpreted independently by two experienced observers; processed images and semi-quantitative data were used for the final interpretation.

Results

In all cases a horizontal or downsloping (9 subjects) or upsloping (7 subjects) ST segment depression of at least 2 mm occurred during the exercise test. The test was stopped in 14 patients for exhaustion and in 2 for ST segment depression >3 mm; in one case, frequent and repetitive ventricular beats were observed during exercise.

The exercise thallium-201 myocardial imaging was normal in 11 patients, and abnormal in 5. A single perfusion defect was found in 2 subjects with 2 defects in the remaining 3. Out of the 8 perfusion defects, 7 were completely reversible and only one was persistent. We observed 2 posterolateral and apical defects and one defect involving the anterolateral, inferior, septal and apical-inferior segments (Table 1). A normal scan was considered to indicate the absence of significant coronary artery disease and the exercise test was therefore judged as false

Table 1. Results of exercise Thallium-201 myocardial perfusion scintigraphy in 16 sportsmen with positive exercise test.

Scintigraphy			Number of subjects
Normal scan			11
Reversible Tl-201 perfusion defects			5
Segments	anterolateral	1	
	apical	1	
	inferior	1	
	septal	1	
	apical-inferior	1	
	posterolateral	2	
Non reversible Tl-201 perfusion defect (apical)			1*

* Subject with reversible posterolateral perfusion defect

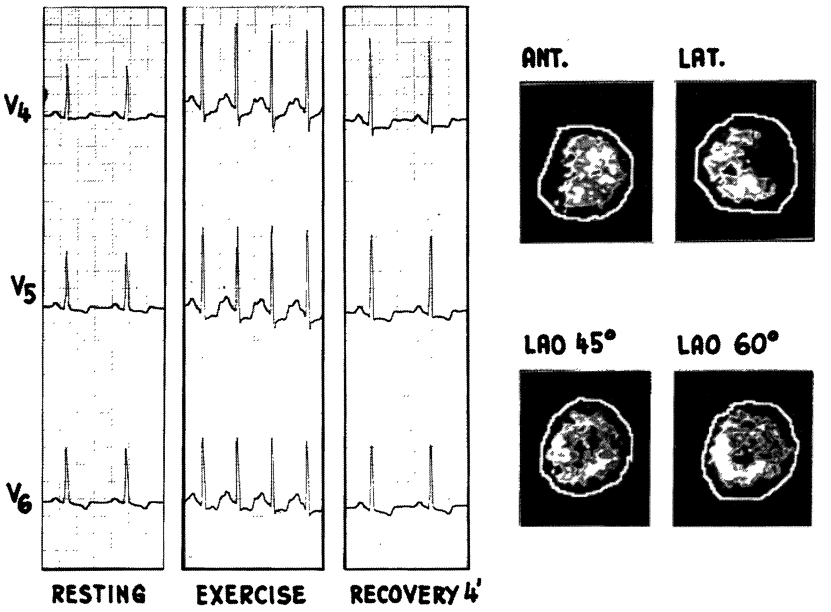

Figure 1. Exercise testing and myocardial scintigraphy of a 35-year old soccer player. Resting ECG shows ventricular repolarization abnormalities. Exercise ECG shows a 2 mm horizontal ST segment depression in leads V4-V6 with recovery within 4 min. The exercise scintiscans in the anterior (ANT), lateral (LAT) and left anterior oblique (LAO) 45° and 60° views reveal homogeneous radioactivity.

positive (Figure 1). Of the 5 patients with an abnormal scan, a high probability of coronary artery disease was considered in 3 cases (Figure 2), while an early congestive cardiomyopathy was suggested in 2 young athletes by both exercise radionuclide angiocardiography and echocardiography showing indices of poor left ventricular function. The former study was performed using the equilibrium gated blood pool technique at rest and during bicycle exercise, with a 45° left anterior oblique projection. Angiocardiography showed areas of segmental hypokinesia while the left ventricular ejection fraction failed to increase from the resting value of 56% and 50% during exercise. Two-dimensional echocardiography confirmed moderate left ventricular enlargement and hypokinesia in both subjects.

There was no relationship between the results of the exercise thallium-201 myocardial scintigraphy and the configuration or the magnitude of the ST segments depression.

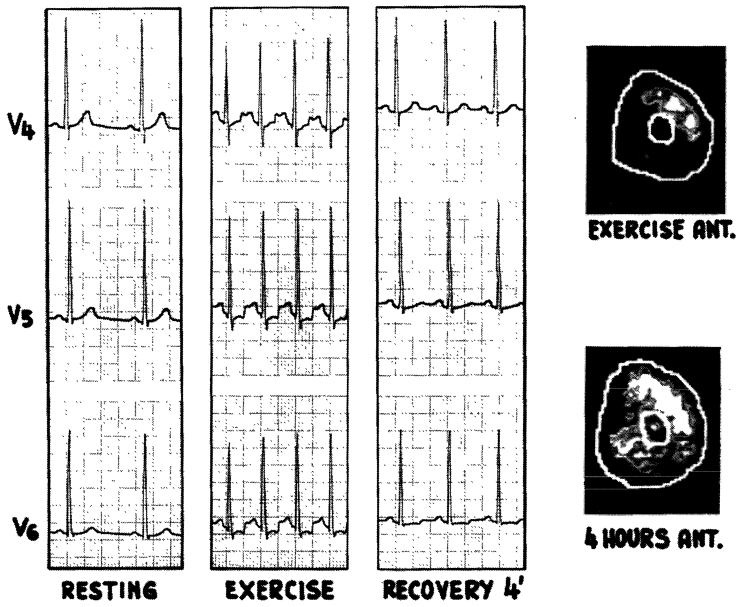

Figure 2. Exercise testing and myocardial scintigraphy in a 46-year old cyclist. The resting ECG is normal. Exercise ECG shows a 1.5 mm horizontal ST segment depression in leads V4-V6 with incomplete recovery within 4 min. An inferior perfusion defect is seen in the scintiscan performed after exercise in the anterior (ANT) view: the 4-h redistribution image is normal.

Discussion

The extension of exercise testing to the field of sports medicine for evaluation of fitness may disclose ischaemic responses to exercise. In such cases difficult problems of clinical clarification arise owing to the poor predictive value of exercise testing in asymptomatic subjects.

Two considerations should be taken into account when evaluating a positive exercise test in asymptomatic athletes. First of all, a high working capacity is not a reliable index of pseudo-ischaemic ST-T abnormalities since it is well-known that some patients with single-vessel coronary artery disease show excellent physical performance. Secondly, a high incidence of false-positive exercise tests in asymptomatic subjects without coronary risk factors has been widely reported in the literature [6]. According to Bayes, the low predictive value of the exercise test is a function of the low pre-test likelihood of coronary artery disease [8]. In view of these considerations, there is a need to clarify the meaning of an abnormal exercise test in asymptomatic subjects studied for fitness evaluation. Owing to its high sensitivity and specificity, exercise thallium myocardial scintigraphy renders

obsolete the pharmacological tests which were previously used to detect false-positive exercise tests. A normal myocardial perfusion imaging virtually excludes the possibility of significant coronary artery disease, thus obviating the need for coronary angiography [4, 7]. On the other hand, the detection of a reversible perfusion defect makes the presence of coronary artery disease very likely if other cardiac abnormalities can be excluded. An abnormal thallium-201 image may in fact be present in patients with bundle branch block, paroxysmal atrial fibrillation, mitral valve prolapse and abnormally elevated left ventricular end-diastolic pressure [1]. Moreover, when echocardiography and radionuclide angiocardiography are employed in conjunction with myocardial perfusion imaging, some forms of cardiomyopathy may be detected at an early stage. The relevance of these non-invasive techniques was clear in 2 of the 5 patients with abnormal thallium-201 scans in whom, in view of their young age, the presence of coronary artery disease was deemed unlikely. The proper utilization of exercise thallium-201 myocardial perfusion scintigraphy, also in combination with other non-invasive techniques, allows us to limit the indications for coronary angiography to those patients with definite thallium-201 reversible image defects.

One limitation of our study was the fact that the 3 middle-aged subjects with positive thallium myocardial imaging did not undergo coronary angiography. Nevertheless, in all 3 cases the perfusion defect involved only one or two segments. For this reason multivessel coronary artery disease, which would have required coronary angiography even in asymptomatic subjects, was very unlikely.

In conclusion, our study demonstrates the value of exercise myocardial perfusion scintigraphy to clarify the meaning of a positive exercise test in athletes. Furthermore the utility of employing a combination of non-invasive cardiological techniques for a correct diagnosis is emphasized.

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Myocardial scintigraphy and cardiospecific creatine kinase responses in female and male athletes after strenuous exercise

M. OHMAN, K. TEO, A. JOHNSON, P. COLLINS and J. HORGAN

Summary

Serum estimations of total creatine kinase (CK) and CK-MB form the most widely used serum determinants of myocardial infarction. We studied 12 female and 15 male athletes 3 days before, and one hour, 24 hours and 96 hours after a marathon race. The males were heavier ($p<0.01$) and trained more intensively ($p<0.001$). Serum estimations of total CK and CK-MB were performed. Mean ($\pm$ SEM) CK and CK-MB became maximally elevated 24 hours after the race. In females CK was 1128 ± 339 IU/l and CK-MB was 13 ± 3 IU/l. In males CK was 1399 ± 348 IU/l and CK-MB was 28 ± 6 IU/l. There was no statistical difference between female and male enzymatic response. Technetium-99m pyrophosphate scintigraphy was normal in both sexes before and after the race. There was no correlation between the weight of the athlete and the maximum CK levels recorded, but the CK-MB response was higher in the well-trained athlete ($r = 0.51$, $p<0.01$). These data suggest that highly trained athletes of either sex are more likely to display false-positive indicators of myocardial infarction using CK-MB measurements.

Introduction

We have previously shown that strenuous exercise, such as marathon running, is associated with elevated total creatine kinase (CK) and CK-MB levels mimicking those seen in myocardial infarction (MI) [8, 9]. As estimations of total CK and CK-MB form the most widely used serum determinants of MI [6] a non-cardiac source for this liberation of CK-MB was suggested by normal infarct-avid scintigraphy and normal levels of alpha$_1$-acid glycoprotein. Similar findings have been reported by others [10].

Recently Apple *et al.* studied the CK-MB content of gastrocnemius muscle in long-distance runners and non-running controls [1]. They found a significantly higher CK-MB content in the muscle biopsy from the runners compared to the sedentary subjects. A spectrum of serum levels of CK-MB exists from mild abnormalities after recreational exercise in unselected volunteers [5] to sharp elevations in marathon runners after competition [8, 9, 10]. Therefore, it would

appear that fitter athletes may exhibit a higher CK-MB response following strenuous exercise. This hypothesis was tested by pooling the data from our two previous studies on cardiospecific creatine kinase responses in male and female athletes.

Methods

The study protocols for the two trials were identical [8, 9]. Twelve female runners (aged 21–38 years) and 15 male runners (aged 25–53 years), with no history of cardiovascular disease, were selected prior to the 1981 and 1982 Dublin City Marathons.

Pre-race evaluations were carried out within 3 days before the marathon race. Evaluation consisted of complete physical examination, resting supine 12-lead electrocardiogram (ECG), chest radiography and Technetium-99m pyrophosphate myocardial scintigraphy. Venous blood was taken from the antecubital vein for estimation of serum enzyme activities. Blood was immediately refrigerated at 4° C, centrifuged and assayed within 24 hours. Total creatine kinase was measured at 25° C by optimized spectrometric method (Boehringer-Mannheim GmbH Diagnostica). The MB fraction was obtained by an ion exchange chromatographic method modified according to Mercer [8]. Technetium-99m pyrophosphate myocardial scintigraphy was performed 40 to 45 minutes after the intravenous administration of 15mCi Technetium-99m stannous pyrophosphate [8]. The images were obtained using a Phocan scanner and reproduced on a film. Repeat scintiscans were taken 48 to 96 hours after the race, this time being the optimal time to detect any myocardial damage sustained during the race [3].

Repeat evaluations were done one and 24 hours after the race, consisting of physical examination, 12-lead electrocardiograms and blood estimations. Final evaluations were done at 96 hours after the race.

Differences between values before and after the race were analysed by paired t-tests. Comparison between groups was by unpaired t-tests. Tests of regression analysis were performed.

Results

The mean ± SD weights of the males were 66.2 ± 6.6 kg and 58.9 ± 5.8 kg in the females ($p<0.01$). The mean average weekly training distances in males were 134 ± 37 km. This was significantly longer ($p<0.001$) when compared to the females (mean 83 ± 26 km). All 27 subjects completed the marathon race. Their finishing times varied from 2 h and 23 min to 5 h and 28 min. No abnormality was noted on physical examination and chest X-rays were normal. The mean (± SEM) total CK and CK-MB responses in the 15 males are shown in Figure 1. Both total

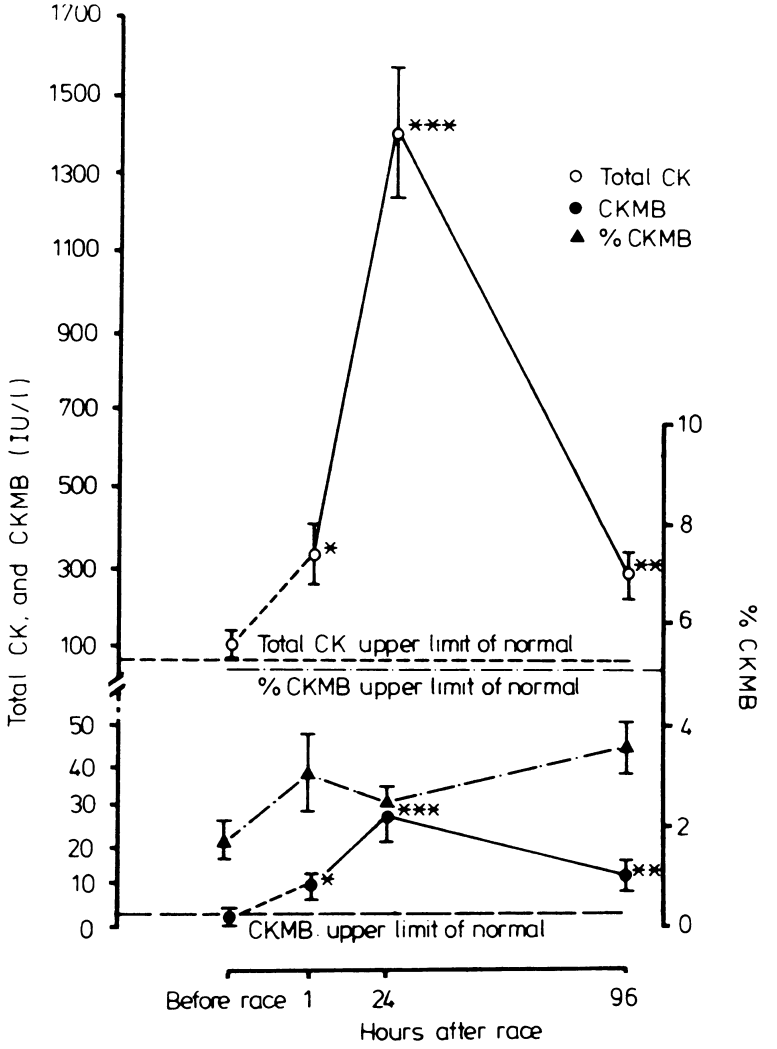

Figure 1. Activities of total creatine kinase (CK) and CK-MB, and percentage of CK-MB before and serially after marathon race in 15 male athletes. Values are means ± SEM. Significance of difference from value before race: *p<0.05; **p<0.01; ***p<0.001. Reprinted with kind permission from British Medical Journal.

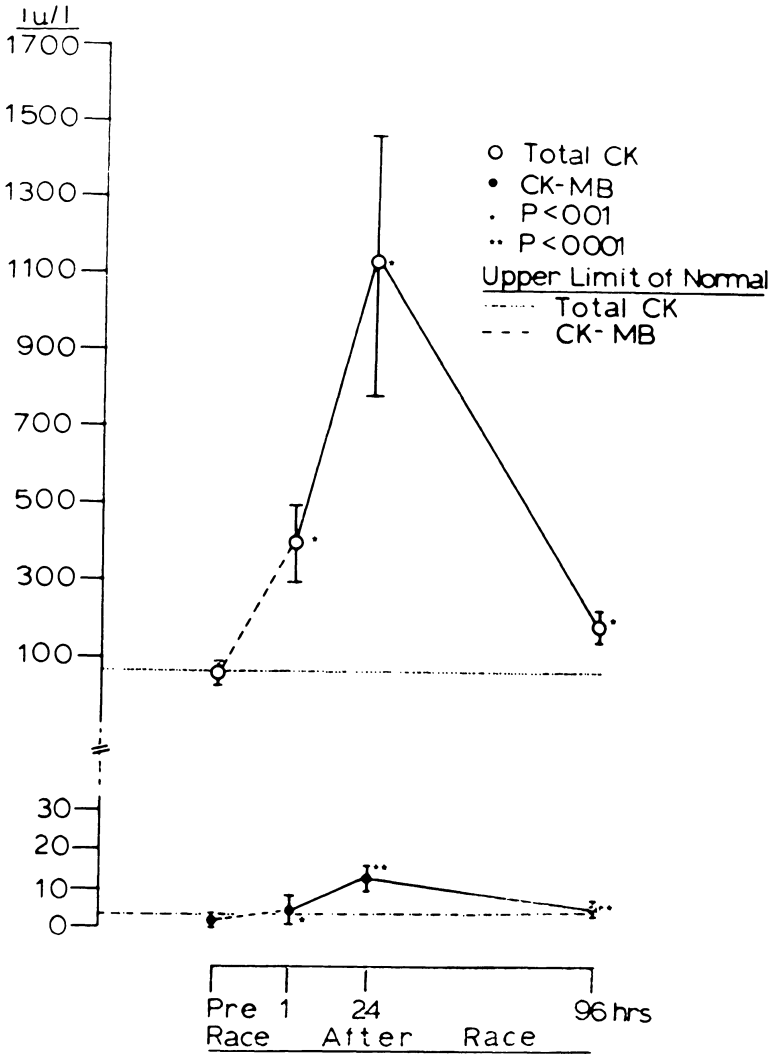

Figure 2. Activities of total creatine kinase (CK) and CK-MB, before and serially after marathon race in 12 female athletes. Values are means ± SEM. Levels of significance of difference from values before race. Reprinted with kind permission from Journal of Sports Medicine and Physical Fitness.

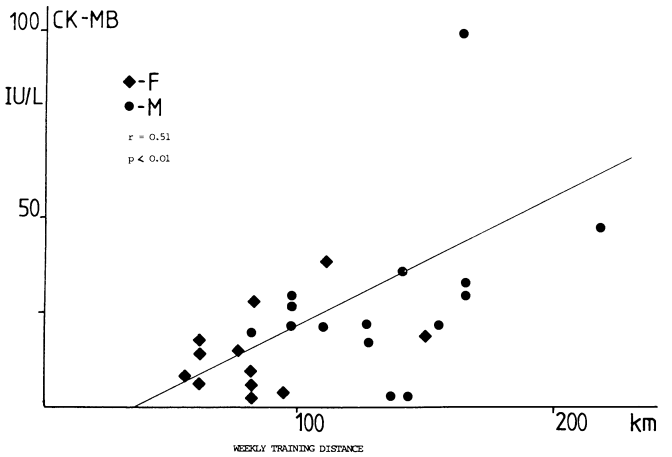

Figure 3. Correlation of weekly training distance and maximum CK-MB response 24 hours after marathon race. n = 27; Correlation coefficient r = 0.51; $p<0.01$. (F = females, M = males).

CK and CK-MB became maximally elevated 24 hours after the race at 1399 ± 348 IU/1 and 27.7 ± 5.9 IU/1 respectively. One and 96 hours after the race 2 and 5 subjects, respectively, showed CK-MB percentages equal to or greater than 5% of total CK value (1 hour: 5.4%, 10.6%; 96 hours: 5.2%, 5.0%, 5.1%, 5.1% and 6.0%), though the means of these percentages were all within the normal range. The mean total CK and CK-MB responses in the 12 females are shown in Figure 2. Similar to the males, both total CK and CK-MB became maximally elevated 24 hours after the race at 1128 ± 339 IU/1 and 13.0 ± 3.0 IU/1 respectively. None of the females had a CK-MB level greater than 5% of total CK. There was no statistical difference between males and females in the maximal response of either total CK or CK-MB.

There was no correlation between the weight of the athlete and maximal total CK response ($r = 0.28$), but the CK-MB response was higher in the well-trained athlete ($r = 0.51$, $p<0.01$) (Figure 3).

Technetium-99m pyrophosphate scintiscans were normal before and after the race in all 27 athletes and showed no uptake patterns indicative of myocardial damage or angina pectoris.

Discussion

The male athletes weighed more and trained more per week compared to their female counterparts. A similar response in total CK and CK-MB to exercise was seen in both sexes. Six of the males showed CK-MB levels greater than 5% of total CK. This being considered to indicate myocardium as the source of this

isoenzyme [10], we utilised infarct-avid scintigraphy to exclude the heart as the source. The diagnostic specificity and sensitivity of Technetium-99m pyrophosphate scintigraphy approaches that of measuring CK-MB in suspected MI [3, 10]. Therefore, an alternative source for the elevated CK-MB levels must be sought. Apple *et al.* suggested the most likely origin of such CK-MB to be skeletal muscle fibre, by demonstrating 7% CK-MB activity in active gastrocnemius muscle in long-distance runners, compared to 1% in non-running controls [1]. Our findings lend support to this contention since the fitter the athlete the higher the serum CK-MB. Furthermore, the weight of the athlete appears to have no influence on the extent of exertional rhabdomyolysis. Conversely, Kettunen *et al.* observed no difference in the CK-MB content of quadriceps femoris muscle between ice-hockey players and non-athletes [4]. The reason for this discrepancy remains unclear but may reflect differences in the relative activity of the muscle groups studied.

The evaluation of suspected myocardial injury in the trained individual is difficult because a wide variety of ECG changes, many of which mimic ischaemia, have been reported in this situation [2, 7]. The demonstration of elevated total CK and CK-MB after strenuous exercise renders them also to be an unreliable indicator of myocardial injury [8, 9, 10]. This study suggests that ancillary diagnostic techniques are required in the diagnosis of MI in highly trained athletes, as they are more likely to display false-positive indicators of MI using CK-MB measurements.

Acknowledgement

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§ 4. ATHLETE'S BRADYCARDIA

Carotid baroreceptor control of heart rate and physical fitness

R. FIOCCHI, R. FAGARD, L. VANHEES, E. BIELEN and A. AMERY

Summary

The carotid sinus baroreceptor reflex control of heart rate was studied in 12 endurance runners, 12 matched controls and in 24 cycling tourists using a variable negative pressure applied through a neck chamber. Baroreflex sensitivity was expressed as the slope of the linear relationship between the strength of the stimulus and the maximal lengthening of the RR interval on the electrocardiogram. Baroreflex sensitivity averaged 6.8 ± 1.1 (SEM) msec/mm Hg in controls, 10.3 ± 1.8 in runners and 7.3 ± 0.8 msec/mm Hg in cycling tourists. No significant differences were observed between the three groups. In single and multiple regression analysis, no significant relationship was found between carotid baroreflex sensitivity and age, blood pressure, resting heart rate, peak oxygen uptake and characteristics of training.

Our results suggest that the so-defined sensitivity of the carotid baroreflex control of heart rate is not influenced by the level of physical fitness. If the training-induced bradycardia is due to a change in the efferent arm of the baroreflex control of heart rate, these alterations do not markedly influence the responsiveness of the system.

Introduction

The mechanism by which physical training reduces heart rate have been extensively investigated in animals and in man. Training increases the parasympathetic and/or reduces the sympathetic output to the heart, and there are arguments that training decreases intrinsic heart rate [5, 9] and also the sensitivity of the sinoatrial node to acetylcholine [3]. These effects modify the efferent arm of the baroreceptor reflex control of heart rate, and therefore, the input/output relationship of the system might be altered. For instance, physical training has been shown to increase baroreceptor sensitivity in a group of post-myocardial infarction dogs [1].

In the present study we altered the carotid baroreceptor input to the heart in athletes and non-athletes, by applying negative pressure to the neck through a

neck chamber. The output, heart rate, was measured to determine whether or not there is an effect of physical training on the sensitivity of the carotid baroreceptor reflex control of heart rate.

Methods

Subjects

Twelve male endurance runners (athletes), aged 20 to 41 years, were studied. They had been running for an average of 6.2 years (range 2–11). As revealed by questionnaire they covered an average of 5780 km in the previous year (range 3300–7500 km). At the time of the investigation they ran 120 km/week (range 20–200 km). Twelve male normal volunteers (controls), matched for age and anthropometric characteristics were studied; they were not involved in competitive sports but moderate recreational sports were not a criterion for exclusion. In addition, we studied 24 male cycling tourists, who were 16 to 60 years old and had been involved in their sport for 7.9 years (range 2–18). They had covered an average of 3890 km in the year before the investigation at an average speed of 26 km/h. At the time of the study they had regained their cycling activities since 13 weeks (range 0–34 weeks) after the last winter resting period, and had covered 1780 km on average. None of the subjects was taking medication.

Experimental protocol

All experiments were performed in the morning, in an air-conditioned laboratory where room temperature was stabilized at 18–22° C. Systolic and diastolic blood pressure and pulse rate were measured after five minutes rest in the sitting position. The routine 12-lead electrocardiogram showed sinus rhythm in all subjects except in one athlete who presented a sinus coronarius rhythm and was therefore withdrawn from the study.

Baroreceptor test
The carotid baroreceptors were stimulated in the seated subjects by the application of a negative pressure to the neck through a neck chamber, as described by Eckberg *et al.* [4]. The neck chamber consisted of an elliptical piece of lead rimmed with sponge rubber and moulded to fit with the subject's mandible, neck, clavicle and sternum. A hole with a diameter of 5 cm in the front part of the neck chamber was connected with a thick wall tube with a length of about 3 meters. At the distal end of the tube a manually operated valve connected a continuously rotating vacuum pump either with the ambient air or with the neck chamber. The power of the vacuum pump was controlled by a speed-regulating rheostat.

Another 3–4 mm hole in the neck chamber was connected through a plastic tube with a pressure transducer (Bentley Trantec Mod. 400). A reference lead from the electrocardiogram (ECG) and the neck chamber pressure were recorded on a Mingograph 81 polygraph at a chart speed of 25 mm/sec. Neck chamber suction was initiated abruptly (the rate of 95% pressure change was −300 to −1000 mm Hg/sec). The equipment was positioned so that the subject could not anticipate the stimulus.

The subjects were first familiarized with the negative pressure and instructed to continue breathing regularly throughout the period of neck suction. Thereafter, 8 stimuli of 15 to 20 seconds duration were delivered in a random sequence in the range between −10 and −50 mm Hg. At least 1 minute was left between the various stimuli.

Exercise test

The athletes and their controls performed a graded uninterrupted exercise test on a treadmill ergometer until exhaustion. The controls ran for 5 min at 7 km/h at 0° inclination for a warming up; the speed was then increased to 11 km/h and at this speed the inclination of the treadmill was increased by 2.5° every 2 min until exhaustion. The athletes ran at 9 km/h at 0° inclination for a warming up, after which the speed was set at 13 km/h and the inclination increased by 2.5° every 2 min. Exercise time after the warming up period was 543 ± 38 (SEM) sec in the control and 699 ± 30 in the athletes ($p<0.05$).

The cycling tourists underwent a maximal graded uninterrupted exercise test on an electrically braked bicycle ergometer. The initial external work load was 70 Watt and was increased by 40 Watt every 3 min. Average exercise time was 1319 ± 28 sec.

Heart rate was calculated from the ECG. Oxygen uptake ($\dot{V}O_2$) was measured continuously using an open circuit method; pulmonary ventilation ($\dot{V}E$) and oxygen concentration were determined by a pneumotachograph and a paramagnetic gas analyzer (Siregnost, Siemens). Peak $\dot{V}E$ (BTPS) and $\dot{V}O_2$ (adjusted to STPD) are the results of the last half minute of exercise. The ventilatory equivalent for oxygen was calculated as $\dot{V}E/\dot{V}O_2$.

Analysis

Baroreceptor tests

RR intervals were measured on the ECG recordings for 10 sec before and 15–20 sec after each stimulus. For each single stimulus the RR intervals in the 10 sec preceding the onset of neck suction were averaged and this average was then used to compute the changes in RR interval following the onset of the stimulus. To quantify the cardiac effect of carotid baroreceptor stimulation we compared the 'response' to neck suction as the maximal $\triangle$RR interval during the first 5 sec after

the onset of the stimulus. Carotid baroreflex sensitivity was defined in each individual as the slope of the linear relationship between the 'response' and the negative value of the neck chamber suction, for 8 stimuli and the zero point. The steeper the slope the greater the cardiac slowing per unit decrease in neck chamber pressure.

Statistical analysis

Statistical analysis was performed using unpaired t-tests and single and multiple regression analysis. The dispersion of the data is given as mean ± SEM and $p<0.05$ taken as the level of statistical significance.

Results

Characteristics of the subjects

As shown in Table 1, the normal volunteers and the endurance-trained runners had comparable anthropometric characteristics. Blood pressure at rest in the sitting position was similar in the two groups while pulse rate was lower in the runners ($p<0.05$). Runners had a higher $\dot{V}O_2$ peak than the matched controls ($p<0.01$) but their peak heart rate and peak $\dot{V}E/\dot{V}O_2$ were slightly but significantly lower. The characteristics of the cycling tourists are also presented in Table 1; no comparison was performed between this group and the other two groups.

Table 1. Characteristics of runners and control subjects, and of cycling tourists at rest and exercise.

	Controls matched for runners	Runners	Cyling tourists
N	12	11	24
Age (yr)	25.1 ± 1.4	25.2 ± 1.2	40.7 ± 2.4
Height (cm)	178.6 ± 1.7	177 ± 2.2	173 ± 1
Weight (kg)	68.7 ± 2.1	64 ± 2.4	73.1 ± 1.7
SBP_s (mm Hg)	133.4 ± 3.4	127.7 ± 2.5	142 ± 2.9
DBP_s (mm Hg)	79.6 ± 2.1	81.9 ± 2.5	92 ± 1.4
HR_s (beats/min)	65 ± 3.0*	55 ± 2.2	67 ± 2
Peak $\dot{V}O_2$ (l/min)	3.6 ± 0.1*	4.4 ± 0.1	3.9 ± 0.1
Peak $\dot{V}O_2$ (ml/min/kg)	53 ± 1*	69 ± 1	54 ± 1.4
Peak $\dot{V}E$ (l/min)	116 ± 6.2	125 ± 5.2	115 ± 3.9
Peak $\dot{V}E/\dot{V}O_2$	32 ± 1*	28 ± 1.1	29 ± 1
Heart rate, peak (beats/min)	197 ± 1.7*	185 ± 2.6	177 ± 2

Values are mean ± SEM; *$P<0.05$ between runners and matched controls. Abbreviations: SBP_s and DBP_s: systolic and diastolic blood pressure in the sitting position; HR_s: heart rate in sitting position; $\dot{V}O_2$: oxygen uptake; $\dot{V}E$: ventilation; $\dot{V}E/\dot{V}O_2$: respiratory equivalent for oxygen.

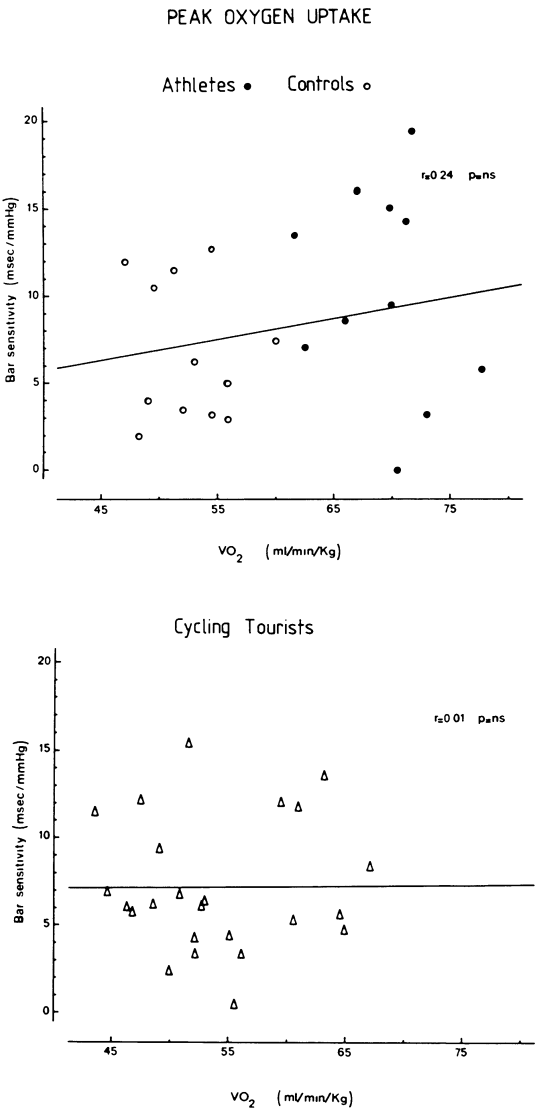

Figure 1. Relationship between carotid baroreflex sensitivity and peak oxygen uptake in athletes and controls (above) and in cycling tourists (under). No significant relationship was found.

The mean negative pressure of all stimuli applied was 26.3 ± 0.9 mm Hg in controls, and 26.7 ± 1.0 and 27.6 ± 1.1 mm Hg in runners and cycling tourists, respectively. Also the time course of the RR lengthening after the onset of the neck chamber suction was similar. Baroreflex sensitivity was not significantly different between the 3 groups, and averaged 6.8 ± 1.1 msec/mm Hg in controls, and 10.3 ± 1.8 and 7.3 ± 0.8 msec/mm Hg in runners and cycling tourists, respectively. Within the groups, single regression analysis did not reveal any significant linear relationship between baroreflex sensitivity and any of the following variables: age, height, weight, systolic and diastolic blood pressure, resting heart rate, duration of sport activity and characteristics of training. Figure 1 shows the relationship between peak oxygen uptake and baroreflex sensitivity for athletes and controls combined, and for the cycling tourists. No significant relationship was found between these two measurements. Furthermore, in multiple regression analysis, no combination of two or three variables was significantly related to baroreflex sensitivity.

Discussion

Physical training induces several physiological adaptations such as a higher level of aerobic capacity, changes in cardiac structure and an increase in stroke volume [2]. Moreover, a low heart rate is associated with greater physical fitness. The mechanisms contributing to the training-induced bradycardia have not been completely elucidated. However, the hypotheses to explain the low heart rate involve the efferent part of the carotid baroreceptor reflex control of heart rate. Indeed, changes in the parasympathetic and/or sympathetic activity [7], a reduction in intrinsic heart rate and a decreased sensitivity of the sinoatrial node to acetylcholine [3], have been proposed. Since the efferent pathway of the baroreceptor control of heart rate is therefore altered by physical training, it is conceivable that the input/output relationship of this control is changed in the trained compared to the untrained.

There are no longitudinal human studies on this subject. In a group of dogs trained daily for six weeks, the sensitivity of the baroreceptor control of heart rate increased [1]. The aim of our study was to investigate whether the carotid baroreceptor-mediated control of heart rate at rest, differs between untrained and moderately and highly trained subjects, and furthermore, to study whether any relationship exists between this autonomic reflex and different variables expressing physical fitness and training.

Our data did not demonstrate a significant difference in the reflex control of heart rate in response to neck suction between athletes and non-athletes. Furthermore, there was no significant relationship between baroreflex sensitivity

and resting heart rate, peak oxygen uptake and several training characteristics. These results do not support the hypothesis that the mechanisms responsible for the training-induced bradycardia, which change the efferent part of the baroreceptor reflex control of heart rate, alter the sensitivity of this system. Alternatively, it could be hypothesized that although physical training changes the efferent part of the baroreceptor reflex arch, some mechanisms, possibly at the level of the central nervous system, keep the input/output relationship of the baroreceptor reflex unaltered.

In apparent contrast to our findings, Stegemann *et al.* [8] demonstrated that endurance training reduces the responsiveness of the blood pressure control system to a decreased transmural pressure, and Raven *et al.* [6] applying lower body negative pressure, found that fit subjects had a significantly smaller increase in heart rate for a given fall in systolic arterial pressure. These experiments investigated the blood pressure and heart rate response to a deactivation of the baroreceptor system. Therefore, they are relevant to explain any reduced orthostatic tolerance of athletes. In our experiment the carotid baroreceptors were stimulated, thereby investigating the response to an activation of the system. Thus, no real contrast is present between our findings and those of Stegemann *et al.* [8] and Raven *et al.* [6].

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Beta-adrenoceptor changes in exercise and physical training

M. OHMAN and J. KELLY

Introduction

Regular physical training leads to adaptative changes in many different body organs [4]. In particular, the effects of regular physical effort on the cardiovascular system have been recognized for many years [5]. An extreme form of adaptation is the development of athlete's heart syndrome. This is characterized by bradycardia, atrioventricular block, ventricular hypertrophy and abnormal repolarization on the electrocardiogram (ECG) [3]. Investigations of athletes with bradycardia and repolarization abnormalities have suggested that there are alterations in the sympathetic nervous system regulation of the heart [34]. However the mechanism by which the bradycardia is maintained at rest remains controversial. Some investigators suggest that the slow heart rate observed in athletes is due to a slow intrinsic heart rate independent of autonomic nerve influences [18].

Studies on adrenergic responsiveness

Using atropine and propranolol to induce pharmacological blockade of the heart, it has been shown that athletes have an increased vagal tone [14, 16]. Ekblom and colleagues put forward the hypothesis of reduced sympathetic, and increased vagal tone, at rest as an explanation for the bradycardia [14]. The lowered sympathetic tone could be due to a decrease in beta-adrenergic activity either because of reduced amounts of circulating agonists such as adrenaline or because of fewer beta-adrenoceptors in the myocardium. If this concept is correct, a lowered sensitivity to the effects of agonists would be expected. Ehsani and colleagues [21] studied changes in heart rate during an infusion of adrenaline in 6 athletes who stopped all training for 2 months. In this small group there was a tendency towards a higher heart rate response to administered agonist 21 and 55 days after cessation of training. This suggests a return to a 'normal' physiological state from a state of lowered responsiveness. Since it has been shown that undertaking regular exercise results in autonomic system changes within 3 weeks [33], it would be reasonable to expect cessation of training to reverse these changes. This reversal may alter myocardial beta-adrenoceptor density and may render the heart more sensitive to the effects of infused adrenaline. Cross-

sectional studies are by their nature weaker than longitudial studies such as the above. Several such comparisons of athletes and sedentary control have yielded different results [19, 20]. The validity of these studies however is in doubt because, as Ehsani noted, there is a great individual variation in response to the tests utilized [21].

In general the consensus of the above studies, while there are some dissenting views, is that the bradycardia seen in athletes is due to an increased vagal tone and a reduced sympathetic tone. A question that arises is how a reduced sympathetic nervous system tone is brought about?

Exercise and catecholamines

It has been shown both *in vivo* [25] and *in vitro* [1] that prolonged exposure to agonist will lead to desensitization of the beta-adrenoceptor. It has been known for many years that exercise brings about an elevation of serum adrenaline and noradrenaline concentrations [5]. Serum concentrations of noradrenaline are directly related to the level of exercise. Mild to moderate levels of activity result in proportional changes in serum noradrenaline concentrations and severe exercise gives rise to greatly elevated levels of noradrenaline [17]. Serum adrenaline concentrations however only become significantly elevated after heavy physical effort [13, 17]. Both catecholamines continue to rise for a short time subsequent to the cessation of exercise [5, 17]. The magnitude of the increase in serum adrenaline and noradrenaline concentrations depends on the relative fitness of the individual studied. Longitudinal studies have addressed this and found that after a physical training program the subjects showed lower catecholamine concentrations for a given workload [11, 33].

While the major source of adrenaline is the adrenal medulla [28], noradrenaline concentrations reflect sympathetic nerve activity in peripheral muscles. A close correlation has been found between sympathetic muscle nerve activity and serum noradrenaline concentrations at rest [29]. It is of note that the heart has also been shown to secrete catecholamines during exercise. Coronary sinus blood concentrations were higher than arterial values of catecholamines when measured during exercise [11]. It may be then, that prolonged exercise is associated with elevated concentrations of both adrenaline and noradrenaline, and that this exposure to agonist may alter beta-adrenoceptor density in the heart.

Exercise and beta-adrenoceptors

Several animal experiments involving exercise training have been used to study the autonomic nervous system and cardiovascular system adaptations. Initial studies on rat myocardium showed that exercise training lowered the tissue

content of catecholamines [12]. Using a different technique Alho *et al.* showed a decrease in adrenergic nerve fibre density on the myocardium in trained rats [2]. From these experiments it was postulated that changes occurred in myocardial beta-adrenoceptor density. When radio-ligand binding techniques became available these were used to study absolute densities of beta-adrenoceptor in the rat myocardium. Sylvestre-Gervais *et al.* observed a down-regulation of adrenoceptors in the rat heart after a 10-week training program [26]. The program consisted of 2 sessions per day of a gradually increasing workload of running for approximately 1 hour. However, two other groups of investigators found no change in beta-adrenoceptor density on the myocardium in a similar animal model [22, 31]. The reason for this discrepancy remains unclear, but the time of exposure to exercise was shorter in these studies which showed no change in beta-adrenoceptor densities. Furthermore the type of exercise utilized in one of the negative studies [31] was swimming rather than running.

In man, where myocardium is not readily available to study beta-adrenoceptors, a lymphocyte model has been used [30]. The human lymphocyte has beta-2-adrenoceptors on the cell surface, which are different from the mainly beta-1-receptors found in the heart. Despite this Fraser *et al.* found an inverse relationship between serum noradrenaline concentrations and lymphocyte beta-adrenoceptor density [15]. Cardiac sensitivity to infused isoprenaline was also positivily correlated with lymphocyte beta-adrenoceptor density [15]. Furthermore Tohmeh and Cryer found that infusions of adrenaline within the physiological range altered beta-adrenoceptor density on lymphocytes in a biphasic manor, with an initial up-regulation followed by down-regulation [27]. These findings suggest that lymphocyte beta-adrenoceptor density reflects cardiac beta-adrenoceptor density, and changes in agonist concentrations, within the physiological range, may alter receptor density.

Using a lymphocyte model we studied the effect of training on beta-adrenoceptor density [8]. Seven male swimmers underwent a 2-month training program. They all showed a marked increase in aerobic capacity (maximal oxygen intake $\dot{V}O_2$ max). Mean ($\pm$ SEM) beta-adrenoceptor density was 1074 ± 52 per cell before training and fell to 458 ± 78 ($p<0.05$) after training. The subjects showing the greatest increase in fitness also tended to display the largest fall in beta-adrenoceptor density (Figure 1). There was a significant correlation between change in $\dot{V}O_2$ max and change in receptor density ($p<0.01$). The change in receptor density could be best explained by prolonged exposure of the receptor to high concentrations of catecholamines, known to occur during exercise. To establish whether short bursts of exercise were also associated with changes in beta-adrenoceptor density, we studied 9 subjects who cycled to exhaustion within 15 minutes of starting [9]. Receptor density on lymphocytes was measured before, immediately after and 25 min after exercise on a bicycle. Resting mean receptor density was 1167 ± 194 per cell. At the end of exercise the density was 2172 ± 583 and after 25 min of rest 778 ± 74 (Figure 2). The responsiveness of the beta-

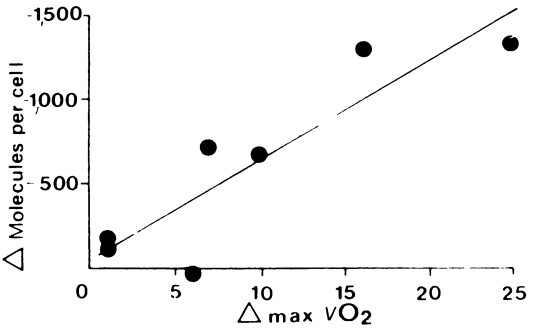

Figure 1. Relationship between change in receptor density (as decrease in the number of molecules of dihydroalprenolol specifically bound per lymphocyte) and change in maximum oxygen intake (as increase in max $\dot{V}O_2$, ml/kg/min) in the 7 swimmers who underwent a 2-month training program. The line of best fit, determined by linear regression analysis, is shown (correlation coefficient = −0.89, $p<0.01$). Reprinted by permission from *Nature* vol. 298, no. 5869, pp 60-2, copyright (c) 1982 Macmillan Journals Limited.

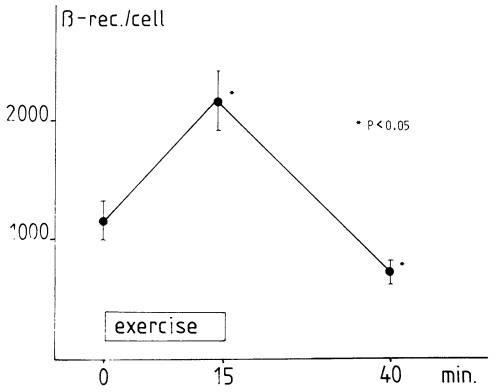

Figure 2. Mean (± SEM) beta-adrenoceptor changes on lymphocytes to acute exercise in 9 male subjects. All changes were statistically significant at $p<0.05$.

adrenoceptor system, as measured by isoprenaline-induced cyclic AMP production, followed the same pattern as the receptor density, suggesting a continuity between the density of and the function of the beta-receptor and adenylate cyclase system. Similar findings have been reported by Brodde *et al.* [7]. Williams *et al.* studied the effect of a 6-week training program of mild to moderate exercise (walking and jogging) in 14 female subjects [32]. Lymphocyte beta-adrenoceptor density was measured before and after the training program. The subjects showed an increase in fitness, which was measured by using maximal treadmill grade obtained, but there was no change in beta-adrenoceptor density. We [24]

however, examined 10 male subjects before and after a marathon training program [10] gradually increasing the weekly running distance. The mean beta-adrenoceptor density before was 1598 ± 117 per cell. One week prior to the marathon this had fallen to 1187 ± 114 ($p<0.05$). During the training period receptor density was also measured before and after a 21 km race. Thus, similarly to our study on acute exercise there was a down-regulation of beta-adrenoceptors on lymphocytes. These data suggest that prolonged exposure to catecholamines desensitizes beta-adrenoceptors at rest and after exercise. The discrepancies between William's study and our findings may be due to different pre-training fitness, level of workload achieved during training, or possibly the time spent exercising. Our marathon trainees spent on average 2 to 3 hours running on most days. As already suggested the time spent exercising may be crucial in observing changes in resting beta-adrenoceptor density. We have also studied the effect of a Cardiac Rehabilitation Exercise Program on lymphocyte beta-adrenoceptor density [23]. The training program consists of a trice weekly 1-h training session, where 75% of maximal heart rate is achieved. After 8 weeks of training the beta-adrenoceptor density fell (1939 vs. 1320 per cell, $p<0.05$), whereas there was no change in a control group who did not undergo a structured training program. These findings are more difficult to interpret as both the formally trained and control subjects showed increased level of fitness after 8 weeks. The possibility of the relative lack of fitness prior to the study must be borne in mind, as all the subjects were studied 6–8 weeks after myocardial infarction or coronary artery bypass surgery.

Conclusion

In conclusion there is evidence that exercise is associated with elevated concentrations of adrenaline and noradrenaline. These physiological stimuli are sufficient to alter beta-adrenoceptor density on lymphocytes. Prolonged exposure to catecholamines which occurs during exercise training is associated with down-regulation of beta-receptors. The desensitized state may have a protective role against the high levels of catecholamines that occur during heavy physical effort. The lowered beta-adrenoceptor density may also partly explain the slow heart rates seen in athletes. However, the variability in the results observed by different investigators need to be explained both in animals and in man. Good models of receptor changes in exercise are still needed to improve our understanding of the sympathetic nervous system adaptations occurring during and after exercise.

Acknowledgment

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CHAPTER II

EXERCISE IN HEALTHY SUBJECTS

Primary prevention of coronary heart disease by physical activity

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Summary

The role of physical exercise and fitness in the development and prevention of coronary heart disease is subject to controversy. In reviewing the large number of epidemiological studies that have considered this relationship, we find several problem areas which could explain the inconsistency of published results: there is no single yet precise method for evaluation of the physical activity level of a given population; most studies include only a limited portion of the physical activity spectrum of their total population, and physical activity is interrelated with numerous other coronary risk factors.

We here present physical fitness results from a prospective study in asymptomatic healthy middle-aged men in whom fitness and activity were measured at entry. Over a 5-year period, the fitness level was predictive of coronary events independently of other coronary risk factors significantly correlated with the incidence of CHD. These results are in keeping with those of the few other studies in this area.

While physical activity should be recommended as a valuable contribution to good health, more research is required into its role in CHD, as well as into the determinants of fitness in the population and to possible mechanisms of prevention of CHD.

Coronary heart disease (CHD) can be prevented by attacking the major coronary risk factors such as elevated serum cholesterol, high blood pressure and cigarette smoking. This has been directly demonstrated in experimental epidemiology studies [9, 10, 13, 16, 25] such as the Belgian heart disease prevention project, a controlled randomized multifactorial intervention trial [13]; in this study, a 25% difference in the incidence of coronary heart disease was observed between the intervention and the control groups.

Besides this direct demonstration, there is a large amount of indirect evidence that CHD is preventable; this is confirmed by the recent decline in cardiovascular mortality in some countries [11].

The role of physical activity and fitness in the primary prevention of CHD is subject to far more debate. This problem can be dealt with from different scientific standpoints; the current presentation is limited to a discussion of results

of epidemiological studies. Rigorous experimental evidence for the protective role of exercise in men is not available. Due to major methodological difficulties, there has never been and probably never will be a controlled, randomized, unifactorial, experimental study of the exercise-CHD hypothesis in normal subjects, and the best available studies are thus the prospective epidemiological surveys. Excellent reviews of these studies [5, 6, 7, 14, 15, 18] have been published, and we will here focus on the difficulties in the interpretation of their results, seeking to explain certain apparent contradictions.

Not all prospective studies have found a significant correlation between physical inactivity and the incidence of coronary heart disease. There is thus some degree of inconsistency in results, however various problems are encountered in interpretation of data from the various studies which are not always strictly comparable.

A first problem relates to the definition of physical activity; the concept of physical activity is generally similar in the various studies, but few of them have used the same method of measurement. Job description, social class and degree of urbanization have all been used as crude, indirect indices of physical activity, while other authors have used a variety of questionnaires on job or leisure-time activities. The diversity of methods used shows the difficulty in assessment of physical activity with a sufficient degree of precision – one possible explanation for differences in results.

A second problem is the fact that the spectrum of activity can range from extremely low (e.g. in disabled persons) to very high (such as in professional athletes). Epidemiological studies are generally focused on selected populations with a far narrower range of physical activity patterns, for instance working populations; many population studies concerning the physical activity-CHD relationship have been carried out in specific occupational categories: London busmen [17], L.A. civil servants [3], Californian longshoremen [19], the Kibbutzim populations in Israel [2] or Italian railmen [23]. Disabled persons were thus excluded from all of these studies, despite the fact that they constitute a substantial proportion of the total adult population. It is well-known that it is more difficult to demonstrate a relationship between an etiological factor and a disease if only a limited proportion of the distribution of the factor is examined, and in particular, if the methodology used to assess the factor is not very precise.

A third problem in the understanding of the correlation between physical activity and CHD is the fact that physical activity is tightly correlated with numerous other major and minor coronary risk factors, including various lipids, insulin levels, blood pressure, body weight and smoking habits. The degree of correlation between these other risk factors and coronary heart disease is stronger than for the physical activity-CHD relationship. Multivariate analysis shows that physical activity per se has only little (and in some studies, no) independent correlation with coronary heart disease; this statistical observation does not, however, mean that physical exercise is of no practical preventative

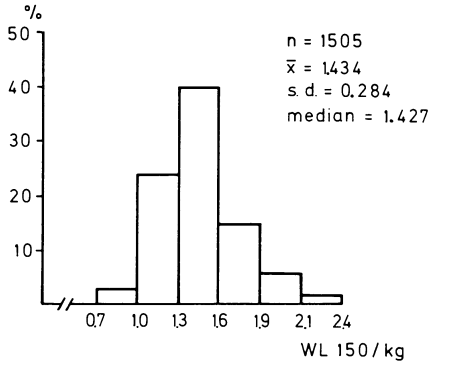

Figure 1. Percentage distribution of WL 150 kg.

value. The physical activity behavioural pattern may well be a carrier for various other CHD risk factors, and if we wish to change these risk factors, we could easily focus on the carrier rather than on the factor itself.

Physical activity has been confused with physical fitness in some studies; although it has been shown that activity is related to the fitness level of a given individual, only a small fraction of the variance of the physical fitness of the population is explained by its activity pattern [4]. Therefore, activity levels and fitness are not necessarily synonymous in a given population, and the question remains as to whether fitness is related to CHD.

The answer to this question has been a long time in coming due to a lack of adequate studies. A positive correlation is suggested by indirect evidence such as the inverse relationship between resting heart rate and the incidence of CHD [12].

In 1975, research workers from the universities of Brussels and Ghent initiated a prospective study in middle-aged factory workers [22]. Using rather stringent selection criteria, physical fitness was measured in 1772 middle-aged asymptomatic healthy men. The criterion for physical fitness was the work load at which a heart rate of 150 beats per minute was attained (WL150/kg, expressed in Watts/kg body weight). Details of the study design and results for CHD prevalence have been published [4, 22].

Figure 1 shows the percentage distribution of the fitness criterion in the 1505 men who reached a heart rate of more than 150 beats/min during the exercise test. The distribution is approximately normal with similar mean and median values, 1.434 and 1.427 Watts/kg respectively.

Other known or suspected coronary risk factors were measured at the initial consultation, and the cohort has now been followed for 5 years with fatal or non-fatal coronary events in 18 subjects during this period. Table 1 compares various baseline measurements for these 18 subjects, by comparison with those who

remained healthy. A multiple discriminant function analysis showed significant differences between those who developed CHD and the others in terms of HDL-cholesterol, smoking habits and the fitness factor. These three factors were significantly and independently correlated with the incidence of CHD. Table 2 summarizes results of prospective studies examining the relationship of fitness to CHD.

All but one of these showed a positive relationship between fitness and CHD, and in the negative Danish study [21] the authors admitted that an analysis with

Table 1. Predictive value of risk factors in a population study of fitness and coronary heart disease.

Risk factors	Incidence of CHD				p*
	Positive		Negative		
	Mean	SD	Mean	SD	
Age, yr	48	4	46	4	NS
Tot-chol, mg%	236	27	232	32	NS
HDL-chol, mg%	46.6	9	54.3	14	.02
Smoking, %	72		45		.03
SBP, mmHg	134.6	14	131.8	13	NS
BMI, kg/m^2	26.9	3.3	25.5	2.9	NS
WL 150/kg	1.34	.22	1.49	.28	.03
Physical activity, AMI	232	140	242	214	NS

* Derived from a multiple stepwise discriminant function analysis. Abbreviations: Tot-chol: total cholesterol; HDL-chol: HDL cholesterol; SBP: systolic blood pressure; BMI: body mass index; WL: workload; CHD: coronary heart disease.

Table 2. The physical fitness-coronary heart disease hypothesis. Prospective studies with direct assessment of fitness.

Author	Population	n	Follow-up (yr)	Relation fitness/CHD incidence	
				Univariate	Multivariate
Wilhelmsen [24]	Göteborg men (54 yr)	793	9	Positive	Positive
Gyntelberg [8]	Copenhagen men	5249	7	Positive	Positive
Schroll [21]	Glostrup population	802	10	Negative	–
Bruce [1]	Seattle heart watch Healthy volunteers (30–64 yr)	2365	5.6	Positive	Positive
Peters [20]	Fire and law enforcement department personnel (35–55 yr)	2779	4.8	Positive	Positive
This study	Healthy factory workers	1505	5	Positive	Positive

maximal aerobic power as the independent variable was impractical since a large number of participants could not manage the exercise test; the high-risk group is constituted of exactly these subjects.

It can be concluded that the available evidence favours an inverse correlation between fitness and coronary heart disease, i.e. that coronary heart disease is less frequent in fitter men. It is obvious that the fitness factor involves more than the activity pattern, and other mechanisms may account for this relationship.

In conclusion, from a strictly scientific standpoint, the question of whether physical activity and fitness protects against CHD remains largely unanswered; in particular, we require simple but precise methods for assessment of physical activity and more research is required into the determinants of physical fitness. Nevertheless, scientists also have a duty to make recommendations to the general public based upon currently available knowledge. From a general health standpoint, regular moderate exercise makes good sense for many reasons. It improves the quality of life by lessening fatigue and by increasing fitness, and it may attenuate several coronary risk factors, thus indirectly modifying the course of CHD. Based on current knowledge, it is recommended that the practitioner prescribe regular exercise as a part of a hygienic CHD prevention program. By recommending physical exercise, we also encourage adequate attention to health, thus promoting changes in behavioural patterns necessary to reduce coronary risk.

In light of the modern definition of health as physical, mental and social well-being rather than merely the absence of disease, physical exercise is accepted and should be recommended as a component of good health.

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Exertional risk factors in apparently healthy males: an interim report

B. DAVIES, W.D. ASHTON and D.J. ROWLANDS

Summary

The purpose of this study was to determine the frequency of exertional risk factors in apparently healthy males during exercise. In a prospective study carried out over 12 months, 323 apparently healthy males, aged 30–65 years, underwent functional/diagnostic exercise testing (FDGXT) in the Department of Biological Sciences. Twenty-six (8%) of the subjects displayed electrocardiographical abnormalities associated with coronary heart disease and of this group, 19 (73%), had one or more conventional risk factors (i.e., cigarette smoking, a family history of coronary heart disease, hypertension, hyperlipidaemia, obesity, and inactivity). Several of our subjects underwent coronary angiography and subsequent coronary bypass grafting. We conclude that the exercise stress test, in conjunction with conventional coronary risk factors, could assist in identifying a subgroup of individuals who would be at a greater risk of developing cardiovascular problems during exercise than the remainder of the population.

Introduction

A substantial amount of evidence supports the view that individuals involved in moderate activity have a lower risk of coronary heart disease [1]. However, several investigators [4, 6, 8] have documented sudden death during exercise and have suggested a small subgroup who are highly susceptible to this catastrophe. It is not known how many individuals die during exercise, but the number is almost certainly underestimated due to inadequate or inaccurate reporting and lack of follow-up investigation. In addition, it is not known how many deaths are exercise-related, i.e., occurring within 24 h following vigorous activity.

Whilst recognizing the important role of exercise in the prevention of coronary heart disease (CHD), we also see the need for medical screening in selected members of the population in an effort to identify the 'high-risk' individual who requires carefully prescribed exercise.

During the past 12 months we have medically screened 323 apparently healthy males to ascertain the prevalence of conventional risk factors. In addition, exercise testing facilitated the assessment of exertional risk factors. This paper reports on our findings to date.

Subjects and methods

Between July 1983 and July 1984, 323 apparently healthy males, aged between 30–65 years, underwent medical assessment in the Department of Biological Sciences, University of Salford. Subjects attended the Department on a voluntary basis and all had expressed an interest in improving their present standard of fitness. There was no definite history of cardiovascular disease, including hypertension, in any of our sample and none had been investigated previously. Eighty % of the sample was drawn from management and executive groups in local industry (Registrar General's Social Classes I and II). The remainder of the sample (20%) was divided equally between social classes III and IV. Subjects were weighed and percentage body fat estimated using the method of Wormsley and Durnin [9]. We regarded obesity as an estimated body fat of 25% or greater.

Other conventional coronary risk factors, i.e., cigarette smoking, hypertension, hyperlipidaemia, inactivity and a family history of coronary heart disease, were recorded for each subject. Prior to a functional/diagnostic graded exercise test (FDGXT), subjects underwent a detailed clinical examination and a fasting blood sample (10 ml) was withdrawn for subsequent haematological and biochemical analysis, including lipid profile.

Following a 12-lead electrocardiogram, subjects underwent a modified Balke walking test on a treadmill. This consisted of incremental increases in gradient ($2^1/_2$%) every 2 min at a constant walking speed of 5 km/h. Throughout the test, selected leads (II, AVF, V5) were monitored simultaneously using a computerized analysis system (Picker International Ltd). Oxygen consumption was recorded every 30 sec by directing the expired air, via a low-resistance valve, into an automatic on-line gas analysis system (Mijnhardt). Blood pressure was recorded 1 min 30 sec into each stage using a mercury sphygmomanometer. The test was symptom-limited and continued until maximum oxygen consumption ($\dot{V}O_2$ max) was attained, unless contra-indications were observed. Immediately following the maximum exercise test, electrocardiographic and blood pressure monitoring was continued during a 2 min walking recovery (5 km/h, 0% gradient) and 6 min of supine rest. Table 1 shows our criteria for an abnormal exercise response.

In the event of a strong indication of left main stem disease, multiple vessel disease or ventricular dysfunction, subjects were referred to Manchester Royal Infirmary for further investigation including echocardiography and/or coronary angiography.

Results

As shown in Table 2, of the 323 subjects who underwent laboratory evaluation, a total of 26 (8%) were considered to have a significantly abnormal exercise test. The age range of this group was between 33–62 years with a mean of 46 years. The

range of $\dot{V}O_2$ max was between 27–57 ml × kg/min with a mean of 42 ml × kg/min. Of the 26 positive tests, 19 (73%) had one or more conventional coronary risk factors and seven (27%) had three or more (i.e., cigarette smoking, hyperlipidaemia, hypertension, obesity, inactivity or a family history of coronary heart disease).

Fourteen (54%) of the 26 abnormal responses to exercise demonstrated significant ST segment depression (2–5 mm) with or without T wave changes. Four (15%) developed ventricular tachycardia and three (11%) frequent ventricular ectopic beats as defined previously. One subject (4%) developed 'normalization' of previously inverted T waves, another a rate-related left bundle branch block (LBBB), and one developed atrial fibrillation. Two of our subjects (8%) had adverse blood pressure changes during the test; one showing an inappropriate rise in BP (systolic BP >230 mmHg), and another a fall in blood pressure. One subject experienced mild chest discomfort during testing.

Table 1. Criteria for an abnormal exercise response.

1. 2 mm or more of horizontal or down-sloping ST segment depression as measured 80 msec from the 'J' point, with or without T wave changes
2. Frequent (>10/min) premature ventricular contractions (PVCs), unifocal or multifocal or occurring in couplets
3. Atrial fibrillation/flutter/tachycardia
4. Second- or third-degree heart block or left bundle branch block (LBBB)
5. Ventricular tachycardia (VT) as defined by three or more premature ventricular contractions (PVCs) in rapid (>120 per minute) succession
6. Ventricular fibrillation
7. A fall in blood pressure or a failure to achieve a systolic BP of at least 160 mmHg during the test
8. An inappropriate increase in BP as defined by a systolic BP of 250 mmHg or greater
9. The development of typical cardiac pain

Table 2. Abnormal exercise responses in 323 apparently healthy males.

Abnormality	Subjects	
	Number	%
ST ± T wave changes	14	54
Ventricular tachycardia	4	15
PVCs ± couplets	3	11
'Normalization' of T waves	1	4
Atrial fibrillation	1	4
Left bundle branch block	1	4
Blood pressure, high	1	4
Blood pressure, low	1	4
Total	26	100

In six (23%) out of the 26 abnormal subjects, ST segment depression was 3 mm or greater, and since there was a high probability that this group would have significant underlying coronary atheroma, they were referred for coronary angiography. Two of these apparently healthy individuals declined this investigation, a fact which is hardly surprising since they were, of course, entirely asymptomatic. Nevertheless, one of these individuals with 4–5 mm ST segment depression subsequently died some 12 months later during vigorous activity. In the remaining four subjects who underwent coronary angiography, one had normal coronary arteries but there was clear evidence of hypertrophic obstructive cardiomyopathy (HOCM). Coronary angiography in the remaining three subjects will be considered in more detail.

Patient 1

BS is a 53-year old advertising executive. Preliminary assessment showed him to have a number of conventional coronary risk factors, i.e., heavy cigarette consumption (40/day), obesity (body fat estimated at 31.5%), inactivity (confirmed by a $\dot{V}O_2$ max of 31 ml/kg/min), type IV hyperlipidaemia and a stressful occupation. His resting electrocardiogram was normal. His exercise ECG showed significant ST segment depression (3–4 mm) in inferolateral leads. Subsequent coronary angiography revealed life-threatening coronary artery disease, with critical stenoses of the left main stem, and the right coronary artery, with additional stenoses in the left anterior descending and diagonal arteries. This subject subsequently underwent successful coronary bypass grafting.

Patient 2

CMJ is a 40-year old managing director. Preliminary assessment revealed a number of conventional risk factors, including obesity (body fat was estimated at 34%), inactivity ($\dot{V}O_2$ max 20 ml × kg/min), strong family history of cardiovascular disease, and a stressful occupation.

His resting ECG was normal. His exercise ECG showed definite ST segment depression (3 mm), and subsequent coronary angiography revealed severe three-vessel coronary disease, with a complete occlusion of the descending branch of the left coronary artery, and a developmentally small right coronary artery. There was, in addition, a marked stenosis of the right coronary artery, proximal to the second right ventricular branch. His situation was regarded as critical and he subsequently underwent successful quadruple coronary bypass grafting, and made an excellent recovery.

Patient 3

A 39-year old lecturer. He also had a number of conventional coronary risk factors, including a type IIa hyperlipidaemia with a blood cholesterol of 10.56 mmol, a strong family history of coronary heart disease, and he was also relatively inactive. His resting ECG was normal, but the exercise ECG showed gross ST segment depression amounting to 4–5 mm. Subsequent coronary angiography revealed evidence of atheroma in all three coronary arteries, although the significant disease was effectively confined to the circumflex system. The most significant lesion was a 90% stenosis in the large obtuse marginal branch, and there was evidence that the circumflex artery itself was extensively diseased. Coronary angioplasty and coronary bypass surgery were considered, but were not recommended at the present time. We have advised the subject to avoid the extremes of physical exertion such as squash, but more moderate forms of activity would seem to be reasonable. The coronary angiograms will be repeated in two years from now in order to assess the progress of the lesions.

Discussion

These results emphasize that there is a subgroup of people who are at a substantially greater risk of dying during or following exercise than the remainder of the population. They suggest the need for greater efforts to identify this group in order that leisure activities can be prescribed on an individual basis.

Our sample was drawn mainly from management and executive groups (social classes I and II) and we accept that our results may not, therefore, be typical of the population in general. In our view, however, this does not negate the validity of the results. There is evidence to suggest that lower social groups will, in fact, have a higher prevalence of disease [3], and screening in this group may, therefore, be expected to yield a higher percentage of abnormalities. In our study, 73% of the 26 abnormal subjects had one or more conventional coronary heart disease risk factors. In addition, the three subjects in whom coronary angiography revealed extensive underlying disease, had between three and five risk factors each. In 23 squash players who died from coronary heart disease, 70% had at least one or more risk factors [4], and in the most recent analysis of the Rhode Island Trial [7], only 7% of the 81 individuals who died during or immediately after recreational exercise had no relevant medical history or coronary risk factors.

Some investigators have recommended exercise stress testing for all first time exercisers over the age of 40 [2], or for any subject with one or more coronary heart disease risk factors [5]. The logistics and cost of implementing such a program would be enormous, although this does not negate the value of such a procedure. We feel that education to sensitize the population to conventional risk factors in order that they can carry out a 'self-screening procedure', is a more

practical and realistic alternative (Table 3). Conventional risk factors such as obesity, a family history of heart disease, inactivity, and cigarette smoking, can easily be identified by the individual. We believe that an individual with two or more of these risk factors (particularly cigarette smoking and a family history of heart disease) should attend his own general practitioner for further evaluation. In the event of the general practitioner identifying further risk factors, i.e., hypertension and/or hyperlipidaemia, this small subgroup could then be referred for more sophisticated screening procedures. The prevalence of coronary heart disease in such a group is likely to be high, and exercise testing is therefore likely to have a high predictive value. Exercise stress testing with subsequent exercise prescription, requires time and expertise. Facilities and personnel are limited in this country and, therefore, should be reserved in the first instance for the high-risk individual.

There is a large and consistent body of evidence suggesting that increased activity decreases the probability of developing coronary heart disease. However, there is also evidence to suggest that exertion can cause sudden death in persons with heart disease. Therefore, it is possible that a sedentary individual with coronary heart disease, who begins activity, can evolve through a period of high-risk and become moderately active, with a corresponding decreased probability of succumbing to the disease. Some authorities have suggested that medical assessment prior to exercise is unnecessary, and individuals who wish to become involved in regular exercise programs should simply use their common sense. We believe that this advice is totally inadequate, since we have demonstrated a significant number of individuals who are apparently healthy, but who would be at serious risk of sudden death.

We believe that a simple, three-stage, screening procedure involving self-assessment, general practitioner referral and exercise stress testing, would help to identify a small sub-population of individuals who would be at high risk during exercise.

Table 3. Three-stage 'screening' system.

STAGE 1	Cigarette smoking Family history of CHD Obesity Inactivity 'Stress'	SELF-ASSESSMENT
STAGE 2	Blood lipid estimation Measurement of BP	GP INVESTIGATION
STAGE 3	Exercise stress testing ± other investigations	SPECIALIST INVESTIGATION

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CHAPTER III

EXERCISE IN CARDIOVASCULAR DISEASE

The role of physical activity in post-infarct patients

G. DE BACKER

Physical activity plays a very important role in the rehabilitation and secondary prevention of patients with coronary heart disease. The purpose of this paper is to summarize only some of these aspects in particular in relation with patients who have suffered from an acute myocardial infarction.

Regular endurance training increases fitness in humans – be it athletes, sedentary men or post-infarct patients. In post-infarct patients this has been demonstrated in several randomized and controlled trials. When fitness is translated in physical work capacity, maximal oxygen uptake or double product for a given load, then we can see that a program of exercise training in the convalescence phase of myocardial infarction increases fitness above what can be expected from the spontaneous evolution.

In Table 1 results are presented from a controlled and randomized trial of the effects of cardiac rehabilitation on fitness [2]. Differences are presented from starting values, in total physical work capacity, the work capacity at a heart rate of 120 beats/min and the rate-pressure product at a workload of 400 kpm. From these results the net effect that can be attributed to the exercise program after having considered what can be expected from the spontaneous evolution as observed in the control group, can be calculated.

The results are comparable with those observed in other studies [9, 14]. The large variation in net effect between studies depends partially on the differences in training program and on differences in criteria that were used in selecting the patients.

These favourable results observed in the convalescence phase after myocardial infarction can be maintained over time. This point is illustrated in Figure 1 with results from another randomized and controlled trial. In the figure the total work performed is presented for the rehabilitation and the control group 1, 2 and 3 years after the acute infarct; the difference between control and rehabilitation group remains clearly present even at distance from the infarct.

Another role that has been attributed to physical activity in post-infarct patients is related to the psychosocial adjustment. However, what has been said and written on this subject is frequently based on subjective feelings and rarely on objective results from controlled studies.

There have been only very few well-controlled and randomized trials on this subject. Some of them did not show any significant difference, possibly due to insufficient sample size or to insufficient discriminating power of the methods that were used to assess the psychosocial condition [3, 10, 18].

Among the controlled trials with positive results there is one in middle-aged coronary-prone men, randomly assigned to an exercise program or a control group [6]. Greater subjective social and psychological changes were found in the exercise group as compared to the non-exercising men. These changes include increased stamina, reduced stress and tension and feelings of better health. In another controlled trial [11], it was demonstrated that among patients with a high neuroticism score, a greater proportion of the rehabilitation group had a good outcome in terms of both physical and emotional stability and social independence as compared to the control group.

Results from studies on the mechanisms by which physical activity induces certain adaptations are less consistent. In the late sixties the pioneers in cardiac rehabilitation were enthusiast about the experimental evidence that exercise training increases coronary collateral flow in dogs after coronary artery constriction. Thirty years later the question if such an adaptation occurs in humans is still unresolved.

Data are lacking or are inconsistent on the effects of exercise on left ventricular performance and myocardial perfusion in post-infarct patients. It is known that by lowering heart rate and systemic blood pressure at any given level of exercise after training the anginal threshold will be increased in patients with a limited myocardial oxygen supply. However the problem whether or not exercise training results in a direct improvement of myocardial oxygen supply is still unresolved.

Using more recent non-invasive radionuclide techniques, the question whether exercise training has a direct effect on the heart, still remains controversial [1, 4, 5, 7, 17]. In a recent study [1] on the effect of exercise training on ejection fraction

Table 1. Effects of cardiac rehabilitation – a randomized controlled trial [2].

Fitness variables	Differences from starting level (%)		
	Rehabilitation N = 29	Control N = 26	Net change*
PWC	+32	+20	+14
PWC hr 120	+26	+12	+14
RPP at 400 kpm	−10	− 6	− 4

* $\frac{\triangle \text{REH} - \triangle \text{Contr}}{\text{Starting level REH}} \times 100$

Abbreviation: PWC: physical work capacity; HR: heart rate; RPP: rate-pressure product.

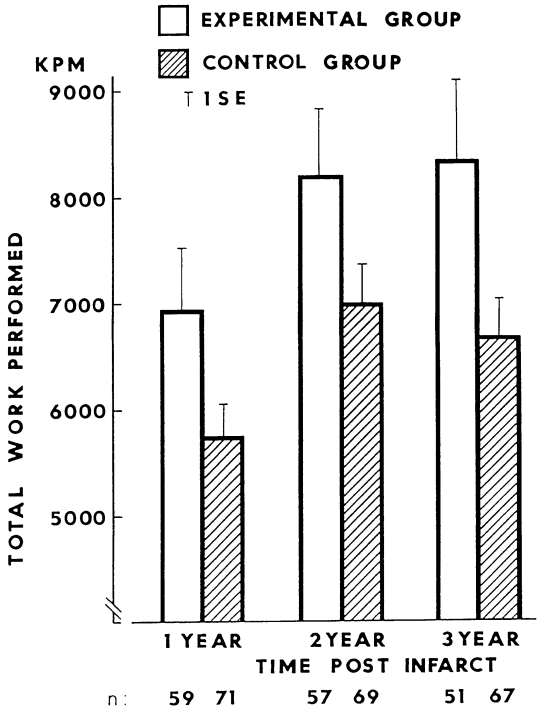

Figure 1. Work, capacity in coronary patients, one, two and three years after an acute myocardial infarction, in a randomized controlled trial on the effect of cardiac rehabilitation.

and end-diastolic pressure in post-infarct patients, the authors concluded that no direct cardiac effects were observed despite a significant training effect.

In another study [4] 146 male volunteers with stable coronary heart disease were randomized either to the exercise program or to a control group. The participants underwent exercise tests initially and one year later. Significant differences were observed between the two groups in aerobic capacity and moderate but significant differences were seen in scintigraphic indicators of ischaemia and ventricular function. The trained group experienced a significant improvement in the thallium-images and the percent change in end-systolic volume at maximal exercise was significantly lower in the trained group compared to the control group.

So, as to the mechanisms through which physical activity leads to increased fitness in coronary patients, there is substantial evidence to believe that most of the benefits are due to peripheral adaptations, but there is a continued need for research using well-controlled randomized trials to clarify the mechanisms whereby exercise training influences the cardiovascular system, particularly now

that new technologies are available to appreciate the ventricular function non-invasively.

Regarding the effect of physical activity after infarction on the prognosis and survival, one has to be very cautious with the data available in the literature. Initially, uncontrolled studies [8] reported encouraging results but in the absence of controlled trials these results were only suggestive. Most of the controlled studies have been either inconclusive or did not show a prolongation of life expectancy in the trained group. However none of the studies had a real good chance to detect a possible effect either because of an insufficient sample size or because of an excessive drop-out rate in the exercise group.

Mortality in post-infarct patients is influenced by so many factors that results from studies with small numbers over short-time periods are difficult to interpret. In Table 2 a summary is given of the 6 studies [9, 12–15, 20] which used a random assignment to the exercise or the control group. None of these trials showed a statistically significant reduction in total mortality; however all but one had a positive trend favouring the physical training group by 15 to 37%.

Finally the question whether there is any danger for exercising post-infarct patients cannot be avoided. There is indeed an increasing amount of evidence that exercise can cause sudden death particularly in coronary patients. A study from Seattle on survivors of out of hospital arrests concluded that 27% of the episodes occurred in association with vigorous exercise [19]. This proportion is 2 or 3 times greater than expected. In another study from Seattle [16] on the risk of primary cardiac arrest during vigorous exercise the authors concluded that the risk of primary cardiac arrest is transiently increased during vigorous exercise. This seems in contradiction with the view from epidemiological studies that vigorous exercise may protect against sudden cardiac death.

The risk of cardiac arrest during vigorous exercise transiently increases especially in men who are habitually engaged in low levels of physical activity.

Table 2. Mortality and physical training of coronary patients.

Trial	Total N randomized	Mortality %		Percent change $\frac{PC - PI}{PC} \times 100$
		Intervention PI	Control PC	
Kentala [9]	298	17.1	21.9	−22
Sanne [14]	315	17.7	22.3	−21
Palatsi* [12]	380	10.0	14.0	−29
NEHDP [15]	651	4.6	7.3	−37
Ontario trial [13]	733	9.5	7.3	+30
Who trial [20]	2602	14.5	17.2	−15

* Coronary mortality.

But the total risk for men who regularly exercise vigorously is markedly reduced compared to less active subjects. So, exercise may be both protective and provocative of sudden death, but the short-term risk is outweighed by the long-term beneficial effects.

The cases of sudden death during vigorous exercise remain very rare as compared to the daily occurrence of sudden death at rest in the community.

In Ghent a total number of 381 cases of acute coronary events were registered in 1983 in the community aged 25–69 years. Fifty-five percent of these events were fatal; 39% of all fatal cases were sudden and unexpected but only 2 cases occurred in association with exercise.

Therefore the message from the apparent paradox, that vigorous exercise may protect against sudden death versus that arrests occur more likely during exertion, is a continued need for supervised programs in coronary patients, a progressive adaptation of coronary patients to exercise and an individual approach considering all pro's and contra's for a given patient.

So, in conclusion there is no definite evidence that exercise prevents reinfarction, sudden death or progression of atherosclerosis in post-infarct patients and such evidence will hardly become available because of major methodological obstacles in studying that question scientifically.

We have to achieve a sound clinical judgement by observing all indirect arguments available from various kinds of research. We should consider physical activity in post-infarct patients as one of the tools available to achieve goals that are set by comprehensive rehabilitation programs in balance with the needs of the individual patient.

Are the goals of cardiac rehabilitation primarily to prolong life or mainly to achieve the highest quality of life? By exercising our patients we know that they will become fit and that they will enjoy the benefits of fitness. This is not a plea against secondary prevention but in my view too much emphasis has been placed on the effects of exercise training on physiopathology and natural history of the coronary disease, and not enough on the effects of exercise training on the coronary patient, on his health, his fitness and his overall well-being.

So even, if we have to admit that there is no definite evidence that exercise prevents reinfarction, exercise training should be considered as one of the most important advices that we can give to selected patients in order to bring them in the healthiest post-infarct condition and to provide them the best chances for enjoying life.

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The organization and implementation of a cardiac rehabilitation program in a district general hospital

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Summary

The use of exercise in the rehabilitation of patients suffering from myocardial infarction (MI) has been increasingly advocated in the United Kingdom. Within the Dudley Health Authority we have been running a regular exercise clinic for post-MI patients since 1977. This paper will discuss the practical guidelines and physiological principles which have been applied to the effective running of this program. Four to six weeks following MI selected patients are recruited to a hospital-based exercise clinic. Physical training is centred upon the use of both interval and continuous aerobic exercise. During the first four weeks of training telemetry is used to monitor for arrhythmias and individual heart rate response to exercise. All physical activities are performed under medical supervision. Following four to six months of training, patients are then transferred to a community based exercise program. Both exercise regimes are supervised by an exercise physiologist and specialist coronary care nurses. Until December 1984 over 462 patients have been processed. Over this period of seven years four of these patients have died from sudden death, usually occurring towards the end of or in the immediate recovery period after exercise. Guidelines for effective and relatively safe exercise prescription are also outlined.

Introduction

The use of exercise has been advocated in the rehabilitation of patients suffering from myocardial infarction (MI) [6, 10]. One of the main concerns with this form of treatment has been the worry that exercise may be potentially harmful [8]. Within the Dudley Health Authority we have been running a regular exercise program for post-MI patients since 1977. During this time 462 patients have taken part. Four sudden deaths have occurred over this period. All of these were considered to be cardiac in origin but one was unrelated to exercise. There was also one episode of ventricular fibrillation which was successfully resuscitated. The program, therefore, has a proven level of safety in a high risk population.

The principles which have led to the successful organization and implementation of this program are outlined.

Organization

At four to six weeks after myocardial infarction, following the physician's recommendation, the patient is invited to attend the exercise rehabilitation program.

At that time each patient is carefully reassessed with respect to a history of:

1. recent chest pain;
2. palpitations;
3. shortness of breath;
4. faintness or dizziness upon exertion;
5. current medication.

Subsequently a twelve-lead ECG is performed and examined for any changes since the record before discharge. If these tests show no contra-indication the patient is enrolled in the exercise rehabilitation program. It should be appreciated that there is considerable individual variation amongst post-MI patients in their ability to exercise (partly related to their previous level of fitness). The contra-indications and special precautions relating to exercise training applied to these patients are listed in Table 1.

Each patient's physical condition must be assessed when planning and implementing an exercise routine. Therefore, every individual has a personal exercise prescription card (Figure 1) which is continually updated with reference to his reaction to exercise as judged by heart rate, blood pressure, perceived exertion and recovery response. The amount of time spent in aerobic exercise is also recorded and modifications are made to the training routine based on each patient's individual progress.

Table 1. Contra-indications and special precautions related to exercise training

Contra-indications

1. Presence of overt signs of heart failure.
2. Occurrence of recent cardiac type chest pain.
3. Presence of systolic hypertension, e.g. more than 200 mmHg at rest or above 250 mmHg during exercise depending on the patient's age and treatment, or an excessive fall of systolic blood pressure during exercise.
4. Frequent multifocal ventricular extrasystoles precipitated by exercise and uncontrolled by medication.

Precautions

Particular care is taken with those subjects

a) taking drugs such as cardiac glycosides, beta-blockers and anti-arrhythmic agents;
b) suffering from other conditions which may interfere with the ability to exercise, e.g. asthma, chronic obstructive airways disease and peripheral vascular disease and arthritis.

Figure 1. Personal exercise prescription card.

NAME:	WEEK 1			WEEK 2			WEEK 3			WEEK 4	
Date											
Pain History											
Pre-exercise blood pressure											
Pre-exercise heart rate											
Running on Spot											
Recovery											
Sit ups											
Wall Bar Step ups											
Recovery											
Bench Step ups											
Recovery											
Bicycle Ergometer Work											
Recovery											
Free running											
Recovery											
Post-exercise blood pressure											
Post-exercise heart rate											
Target heart rate											
Aerobic Time											
Rate of perceived exercise											
ECG report											
Drug therapy											
% Body Fat											
CRI											
GROUP											

For the first four to six weeks of training continuous electrocardiographic observations are made using telemetry with ECG strips taken before, during and after exercise. Blood pressure is also measured at rest, during and following exercise. Throughout the training session, apart from the exercise physiologist, a physician and a specialist coronary care nurse are present. A portable defibrillator and resuscitation equipment with an assortment of emergency drugs are to hand during each of these sessions.

Principles of effective exercise

Each exercise session should include:

1. A warmup period;
2. A work period centred upon the development of aerobic capacity;
3. A recreational period designed to provide enjoyment;
4. A warmdown period.

When training the post-MI patient the following aspects of exercise should be avoided:

1. Heavy strength training routines involving the increasing use of isometric muscle contraction. (This activity leads to a rise in the diastolic blood pressure and a marked increase in the pressures within the chambers of the heart [6]).
2. Breath holding during the performance of any exercise which causes increased intra-thoracic pressure, thereby effecting right ventricular filling [6].
3. Work using anaerobic energy to any marked degree causing an excessive heart rate response and an excessive demand on ventilation [6].
4. Sudden and sharp surges of high intensity exercise followed by equally sudden cessation of exercise. This type of activity may place undue strain upon the heart and reduce the working muscles ability to support venous return [6].

Mode of exercise training

The basic theme of an exercise regime is to increase the patient's aerobic capacity [1, 2, 4, 5, 6]. This can be accomplished using either 'intermittent' or 'continuous' forms of training [2].

During the early months of conditioning it is possible to utilize a major portion of the oxygen transporting capacity by the use of intermittent forms of training. The effectiveness of this technique in improving O_2 transporting capacity will depend upon the ratio of work to recovery intervals together with the intensity and type of exercise being performed. The time spent on initial work bouts should be accompanied by an equal or slightly longer recovery period [9].

This approach provides a gradual acclimatization to physical work during the early months of conditioning. Following the successful completion of this first section of the training program, where gradual reductions in the recovery intervals between work periods may be made, more continuous forms of aerobic training may then be adopted. The early use of interval training as the main form of aerobic exercise possess several distinct advantages. In particular, the maintenance of stroke volume during the recovery intervals and the benefit to coronary blood flow by increased diastolic filling time supports the suitability of this mode of exercise in the conditioning of the post-MI subject.

Intensity of exercise training

Training intensity should be aimed at achieving 50–70% of the patient's functional work capacity [9]. The exact training threshold should be determined through careful reference to each patient's individual clinical and physiological status. It has been suggested that prescription of exercises for the post-MI subject on an individual basis using a percentage of maximal functional capacity reduces the chance of untoward events and maximizes training benefits [5]. The exercise should progress gradually from low, to middle, to high intensity and in some patients this may take as long as 3–4 years to develop fully.

Duration and frequency of exercise

The duration of work is eventually built up to exceed 30 min during each exercise session in order to develop positive increments in cardiovascular fitness. This 30 min period may comprise either of intermittent work bouts of up to 5 min duration with short recovery periods or more continuous forms of training. This again will depend on the clinical and physiological status of each patient and the amount of time previously spent in training.

Each patient should attend a training session at least three times per week. This represents the minimum frequency of training required to achieve a beneficial effect [2, 4, 6, 9].

Recovery during and following exercise

Patients should be instructed to walk at their normal pace between higher intensity aerobic work bouts. The regular continuation of the muscle pumping action at a reduced rate encourages more effective venous return to the heart by avoiding venous pooling in the capacitance vessels thus easing the work of the heart and lungs.

Type and performance of exercise

Each exercise session commences with a gentle warm up concentrating on increasing flexibility of the major muscle groups by the use of static stretching. Ballistic stretching activities can often cause small tears at the site of the musculotendinous junction. This may result in painful injury. Alternative forms of non-weight bearing exercise (e.g. bicyle ergometer) may be used to allow a continuation of training to occur despite such injury – minimizing any loss in cardiorespiratory fitness. The aerobic work session follows, using a combination of bench stepping, wall bar stepping (which involves upper and lower limb movement, utilizing total body mass), running (on the spot and around a specified circuit), stationary bicycle ergometer work and sit ups; with recovery periods between each activity. This combination of exercise encourages the development of cardiorespiratory fitness and also reconditioning of the local musculature.

All exercises are performed in a rhythmical manner with no sudden cessation in work effort. This approach to exercise provides continuous support for venous return to the heart.

Changes in the exercise prescription should be made in the light of the patient's progress. Simple practical assessments of heart rate, level of perceived exertion, along with blood pressure response are used to guide these changes.

Occasionally temporary reductions in workload or an increase in recovery periods may be necessary to avoid complications such as excessive tachycardia, arrhythmias, ischaemic episodes or abnormal blood pressure responses. These reductions may then be followed by further conditioning of the patient with no adverse effect.

Community exercise training

The initial exercise program which takes place within the hospital under close medical supervision lasts for 4–6 months depending on each patients progress. As stated previously, a maximal training effect is achieved following three years of regular controlled exercise. With the limited resources available to a district general hospital in the U.K. and with the regular influx of new post-MI patients, it was recognized that a long-term community-based program was both commendable and required. The positive benefits experienced by the patients themselves also provide the motivation for the establishment of this community-based program (The Cardirian Club).

We were fortunate to be allowed the use of a gymnasium at a Local Institute of Higher Education with its excellent facilities. This club is administered and financed by the patients themselves thus providing them with a sense of responsibility, independence and self-confidence. This encourages their commitment to continuing exercise and a healthy life style.

Community exercise is supervised by the same hospital-based team and the same principles are applied. In addition education is given to patients and close family covering cardiopulmonary resuscitation, the principles of safe and effective exercise and healthy living. This community program has provided a basis for social interaction between club members and their families, promoting a positive outlook for all concerned.

The successful application of these principles has led to some members completing a ten-mile road run, a remarkable achievement in a country with one of the highest mortality rates for ischaemic heart disease. This club represents the final stage of exercise rehabilitation whereby the post-MI patient can train within a gymnasium outside the hospital setting but with qualified supervision and a confident approach to regular exercise.

Comments and observations

Although other post-myocardial infarction exercise programs have advocated more continuous forms of exercise training, we have found that the use of early intermittent training offers safe and effective conditioning. At a later stage more continuous forms of training are utilized.

Four deaths have occurred amongst patients on our program over an eight-year period. Three of these deaths have been directly related to exercise. Two of these deaths occurred 12 months after the initial infarct, and the other after 6 years. All of them had demonstrated a positive response to exercise rehabilitation, but two of them had experienced recent chest pain prior to the fatal episode and had failed to notify the program supervisor. The arrests occurred late in exercise and in two of the cases were related to the immediate recovery period.

These deaths coupled with the successfully resuscitated occurrence of ventricular fibrillation in one other patient on the hospital program which also occurred during the recovery phase of exercise, suggests that the recovery period requires close observation and vigilance.

The cause of death in two of these late episodes revealed no acute infarction and presumably must reflect a rhythm disturbance. We feel that this supports the continuing supervision of the community program by trained and experienced staff. The mortality, however, is relatively low in this high-risk population and supports the principles that we have used in organization and implementing this exercise rehabilitation program in a District General Hospital.

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Correlates of the effect of physical training in cardiac patients

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Summary

A retrospective analysis was performed in 118 patients with heart disease, who were trained for 3 months. Peak oxygen uptake ($\dot{V}O_2$) increased with 38%. Multiple regression analysis revealed that the gain in peak oxygen uptake after the training program was more important when the initial peak oxygen uptake was low, when a history of angina and dyspnoea were absent and when the training intensity and frequency was high ($R = 0.62$). It was not related to the type of myocardial infarction, peak CPK, cardiac function, medical treatment, ST depression or arrhythmias.

In conclusion, these data indicate that both training characteristics and the condition of the patient before starting the program are related to the training effect, at least in the population studied.

Introduction

Physical training in patients with a previous myocardial infarction, after coronary artery bypass surgery, or certain other cardiac diseases, is widely used. However, it is still unclear which factors determine the changes of physical capacity observed after training. Therefore, we correlated the changes in peak oxygen uptake, observed after a 3-month physical training program in cardiac patients, with several factors related to the patient characteristics at entry and to the characteristics of the training program.

Methods

Patients

Among 298 male patients with ischaemic heart disease, referred to the cardiac rehabilitation unit in the period 1979–1983 118 patients met the following criteria

for acceptance in this retrospective analysis. They performed a graded exercise test until exhaustion as well before as after 3 months of physical training; patients with a history of angina were included when angina did not limit the exercise tests. Medical drug treatment was not changed during the training period.

The age of the patients averaged 53 (range 33–67) years, weight was 71 (51–115) kg and blood pressure 130 (96–190)/88 (68–116) mm Hg. Eighty-six patients had suffered from a myocardial infarction (MI) of whom 17 had undergone coronary artery bypass surgery (CABS). Eighteen underwent CABS without a previous MI. Six patients had only angina without MI or CABS. Two patients were referred for hypertension, 4 for Da Costa syndrome and two after valve replacement. Also 29 patients with either a previous MI or CABS had angina pectoris which did however not limit the exercise tests.

Testing procedure

Before starting the training program each patient performed a graded exercise test on the bicycle ergometer (Siemens 380B) in an air-conditioned laboratory (temperature 18 to 22°). The initial work load was 20 Watt and the load was increased with 30 Watt every 4 min until exhaustion. Oxygen uptake ($\dot{V}O_2$) was continuously measured using an open circuit system (Siemens FD84). Heart rate (HR) was calculated from the continuously recorded electrocardiogram (ECG). The same testing procedure was performed after the 3-month training period.

Training program

The physical training program was designed so that patients would exercise indoors for 3 months, 3 times weekly, for a total duration of 75 minutes for each exercise session. Each session consisted of cycling, rowing, armwork, running and predominantly isotonic calisthenics. The initial training intensity was adapted to 60% of the measured maximal exercise capacity for each patient and was increased gradually during the training period.

Data analysis

Changes in oxygen uptake at peak exercise over the training period were related to various factors using single and step-up multiple regression analysis. The factors considered are for all subjects: age, weight, pre-training systolic and diastolic blood pressure, training attendance and intensity and pre-training peak oxygen uptake; for the patients with a previous MI or CABS: the delay between this cardiac event and onset of training and peak CPK for the patients with a previous MI.

For the comparison of the training response of various subgroups, one way analysis of variance was used. The dispersion of the data is given by standard error of the mean (SEM).

Results

The average duration of the training period was 14.1 ± 0.2 weeks and the attendance frequency was 2.4 ± 0.05 times per week. The average intensity of training defined as the ratio of the average exercise heart rate during the last three weeks of rehabilitation over the peak heart rate at the pretraining exercise test was 99 ± 2%.

In the total group peak oxygen uptake increased with 38% (Table 1). Also the peak external work load of 127 ± 3 Watt increased with 38% to 175 ± 3 Watt. The increase in exercise capacity was associated with a higher peak heart rate after training, but the peak oxygen pulse still increased with 23%. The changes in peak oxygen uptake were similar in patients with a myocardial infarction, with coronary artery bypass surgery and with both. In Table 2 the results of various subgroups are compared. Only patients who complained of dyspnoea before starting the training program had a lower increase in peak oxygen uptake after training ($p<0.05$). Figure 1 illustrates that there was no difference in the response to training according to the resting ejection fraction obtained during catheterisation in the non-operated patients.

Single regression analysis (Table 3) showed that the increase in peak oxygen uptake was positively related to training characteristics, such as attendance ($r = .31$, $p<0.001$) and training intensity ($r = .27$, $p<0.01$) and inversely related to the initial exercise capacity ($r = -.27$, $p<0.01$). Multiple regression analysis revealed significant partial correlation coefficients between the increase in peak oxygen uptake and initial peak oxygen uptake ($r = -.32$), training intensity ($r = .29$), presence of complaints of angina pectoris ($r = -.25$) or dyspnoea ($r = -.23$) and training frequency ($r = .23$) ($R = 0.62$, $p<0.001$).

Table 1. Oxygen consumption, heart rate and oxygen pulse at peak exercise before and after physical training (n = 118).

	Before training	After training	Difference
Peak $\dot{V}O_2$ (ml/min)	1159 ± 38	2150 ± 42	591 ± 31***
Peak $\dot{V}O_2$ (ml/min/kg)	22.1 ± 0.5	30.2 ± 0.6	8.2 ± 0.44***
Peak HR (beats/min)	128 ± 2	144 ± 2	16 ± 2***
Peak oxygen pulse (ml/beat)	12.3 ± 0.3	15.1 ± 0.3	2.8 ± 0.2***

Data are means ± SEM.
*** P<0.001.

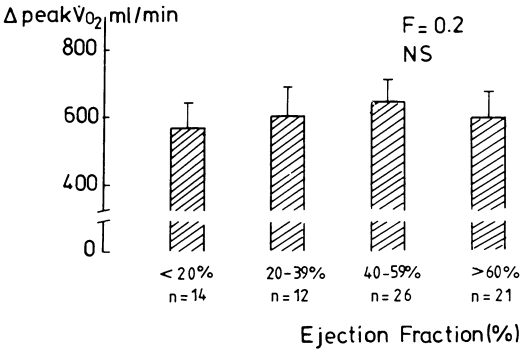

Figure 1. Comparison of the effect of training on peak oxygen uptake in 4 groups of patients, divided according to their left ventricular function. Only the resting ejection fractions of the non-operated patients were considered in this analysis.

There was no relationship between the change in peak oxygen uptake and the time between the event and admission to the training program, neither in single nor in multiple regression analysis. This time averaged 143 ± 18 days.

When the analysis was performed using the change in peak oxygen pulse to express the training effect, similar results were found.

Table 2. Changes in peak oxygen uptake (ml/min) after physical training: comparison between groups.

Patients with transmural myocardial infarction (n = 68)	569 ± 47	NS	587 ± 70	Patients with non-transmural myocardial infarction (n = 18)
Patients with inferior myocardial infarction (n = 35)	557 ± 55	NS	589 ± 44	Patients with anterior myocardial infarction (n = 47)
Patients treated with β-blockers (n = 69)	607 ± 40	NS	572 ± 53	Patients not tread with β-blockers (n = 49)
Patients treated with digitalis (n = 23)	616 ± 79	NS	589 ± 35	Patients not treated with digitalis (n = 95)
Patients with significant exercise induced ST depression (>1 mm) (n = 23)	627 ± 72	NS	482 ± 34	Patients without significant exercise induced ST depression (n = 95)
Patients with frequent* rhythm disturbances (n = 20)	525 ± 78	NS	605 ± 34	Patients without frequent rhythm disturbances (n = 98)
Patients with a history of angina pectoris (n = 35)	533 ± 63	NS	616 ± 35	Patients without a history of angina pectoris (n = 83)
Patients with complaints of dyspnoea (n = 14)	422 ± 92	P<0.05	614 ± 32	Patients without complaints of dyspnoea (n = 104)

Data are means ± SEM

* Frequent rhythm disturbances were defined as supraventricular or ventricular arrhythmias which occurred at one of the exercise tests with a minimal frequency of at least ten or more or as multifocal and/or couplets of ventricular extrasystoles.

Discussion

In the present investigation, the training program was effective in increasing peak oxygen uptake and exercise duration with 38%. These increases were associated with higher peak heart rates after training, probably due to less fear, less muscle pain and/or a better motivation to exercise up to exhaustion after the training period. The change in peak oxygen pulse is probably a better estimate of the true training response; it also increased, with 23%. However, since the analysis on the change in peak oxygen pulse provides the same results as the one using peak oxygen uptake, only data of the latter analysis are presented.

The increase in peak oxygen uptake after the training program was positively related to such training characteristics as training intensity and attendance, which is in agreement with other reports [3, 5, 6]. Also the negative correlation of the increase in peak oxygen uptake with the pre-training peak oxygen uptake is generally observed [7, 10]. Complaints of dyspnoea and of angina before starting the training program were negative predictors for the increase in oxygen uptake after training. The latter is in apparent contradiction with findings of Detry *et al.* [1] who reported a more pronounced increase in symptom-limited exercise capacity after training in patients with angina pectoris than in post-myocardial infarction patients without angina pectoris. It should be stressed, however, that the patients with angina in our study reported a history of angina but were not limited by angina during stress-testing.

Other factors were not related to the effects of training: the type of myocardial infarction, left ventricular function as judged from the ejection fraction on the angiogram, and the occurrence of significant ST segment depression or arrhythmias at the exercise test. Also patients with a myocardial infarction re-

Table 3. Single regression equations (Y = bX + a) between changes in peak oxygen uptake (Y) and several characteristics (X).

X	b	a	n	r
Age (yrs)	−2.37	717	118	r = −.05
Weight (kg)	3.7	330	117	r = .11
Pre-training systolic blood pressure (mmHg)	−2.3	894	118	r = −.14
Pre-training diastolic blood pressure (mmHg)	−1.5	722	118	r = −.05
Delay between cardiac event and onset of training (weeks)	−.17	617	104	r = −.08
Peak CPK (U/l)	0.06	535	66	r = .11
Training attendance (n per week)	233	41	112	r = .31**
Training intensity (%)	6.32	−34	112	r = .27**
Pre-training peak $\dot{V}O_2$ (ml/min)	−.21	+926	118	r = −.27***
Pre-training peak $\dot{V}O_2$ (ml/min/kg)	−21.1	+1059	117	r = −.35***

Abbreviations: n = number of observations; r = correlation coefficient. ** $P<0.005$; *** $P<0.001$.

sponded similarly than patients who had undergone coronary surgery, whether or not preceded by an infarction.

Also age was not significantly related to the training response ($r = -.05$). This indicates that alo elderly patients may benefit from training, which agrees with a previous study on the patients over 60 (2). The pretraining systolic and diastolic blood pressure, weight and the time interval between the occurrence of the cardiac event and the start of the training program (4) were also not related to the training effect. Finally, there was no relationship between the training effect and digitalis- or beta-blocker treatment, the latter confirming previous studies [8, 9].

When interpreting these results, one should however bear in mind the defaults of a retrospective analysis. Also the present conclusion can only be applied to the patients referred to the training program; patients with severe heart failure, instable angina, severe hypertension, a.o. were not referred to the training program. Furthermore the data of those patients who dropped out of the program ($n = 57$), of those where the medication was changed ($n = 69$) and those who did not perform maximal exercise tests as well before as after the training program ($n = 54$) were excluded from analysis. Therefore the present analysis was performed in a selected group of patients.

In conclusion, this analysis identifies some training characteristics and some factors related to the condition of the patient before starting the training program, which are related to the training effect, at least in the studied population.

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Coronary collaterals: protective effects during physical training?

R. WOLF and P. LICHTLEN

Summary

In 47 patients with proven coronary heart disease a standardized bicycle ergometric test was performed before and after a six-week physical training program, consisting of twice-daily jogging or cycling for 40-min periods. Maximal workload achieved, heart rate, exercise duration and the systolic pressure-rate product were determined at the time of development of limiting symptoms and/or ischaemic ST depression, or when the age-predicted maximum heart rate was reached. Patients were angiographically separated into groups with proximal occlusion of one major coronary vessel and complete collateral filling (group A: LAD 15, LCx or RCA 11) or high-grade (>75–90%, mean: 88.3%) stenosis without collaterals (group B: LAD 9, LCx or RCA 12). In both groups the remaining vessels and post-stenotic wall motion were normal. There were no significant differences in age, sex distribution, site of diseased vessels or ejection fraction. Maximal heart rate and the double product remained unchanged after training in both groups, and did not differ significantly between the two groups. Capacity and duration of exercise significantly increased with training. The frequency of ST segment depression was comparable in both groups. In patients with a positive exercise ECG, the ischaemic threshold, evaluated in terms of the maximal heart rate and the double product, remained constant after training and showed no significant differences between both groups. We thus conclude that under these specific anatomic conditions, collaterals show a significant but limited protective effect during excessive stress, maintained after a short-term training program.

Introduction

The pathophysiologic relevance of coronary collaterals in chronic coronary heart disease remains subject to debate [5, 8]. It is generally accepted that coronary blood flow through large collateral vessels may be sufficient to maintain a normal resting oxygen supply and myocardial wall function [1, 4, 12], however this metabolic balance between oxygen supply and demand is not representative of the ischaemic situation under conditions of increased energy requirements. Fur-

thermore, one would assume that a physical training program could stimulate the growth and functional capacity of coronary collaterals [10, 11]. Conflicting results are due primarily to methodological factors such as analysis of collateral perfusion in incompletely occluded coronary vessels, so that the separate contributions of collateral and antegrade blood flow cannot be clearly differentiated. Hence, we here investigated the clinical role of coronary collaterals in patients with totally occluded coronary vessels without myocardial infarction, compared to subtotally stenosed coronary vessels without collateral perfusion. We sought to determine whether an entirely collateral flow can exert a significant preventive effect against stress-induced ischaemia, by comparison with high-grade obstructed coronary arteries without collateral perfusion. This was studied by comparison of the exercise capacity and the ischaemic threshold in patients with and without collateral supply. Furthermore, the effects of physical training were evaluated in the two groups.

Methods

Exercise studies were performed in two groups of coronary patients, defined by the following angiographic criteria:

Group 1: proximal complete obstruction of one major coronary branch with all perfusion by large collaterals, originating from non-obstructed branches;
Group 2: high-graded (>75–90%) obstruction of one major coronary artery without visible collateral filling on angiography.

In all patients the remaining coronary arteries had no significant obstructions and regional wall motion of the post-stenotic left ventricular segment was normal or only minimally reduced.

Both patient groups underwent upright bicycle ergometry with increasing workloads on an electrically braked ergometer. Workload increments of 25 Watt were added every 2 min until the development of limiting chest pain, dyspnoea, fatigue, ischaemic ST segment depression, or when the age-predicted maximal heart rate was reached. Heart rate, systolic blood pressure, and the electrocardiogram were recorded at the end of each minute of exercise and upon the onset of ischaemia. The onset of an ischaemic reaction was defined as the moment at which the subject developed significant ST segment depression (>0.1 mV) in at least 2 leads, independently of angina pectoris. Maximal workload, exercise duration, heart rate, and the systolic pressure-rate product were determined.

Subsequently, both patient groups were referred to a six-week exercise training program. Subjects trained for 40 min twice a day, 5 times weekly. Each training session consisted of warmup and cooldown periods, jogging or stationary cycling. Patients exercised at or near their maximal heart rate before the onset of

ischaemic ST depression. During the training period each patient received nitrates and, if necessary, calcium-antagonists in an individualized dosage to permit exercise without anginal pain. No patient required additional treatment with beta-blockers. At the end of the exercise training period each patient underwent a second symptom-limited bicycle stress test, using the initial exercise protocol. All anti-anginal drugs except nitroglycerin were withheld for 48 hours prior to the first and second exercise test.

Results

Clinical and angiographic results for both groups of patients, those with and those without collaterals, are summarized in Table 1. There were no significant differences in terms of distribution by age, sex, localization of diseased coronary arteries or the ejection fraction. The degree of stenosis in patients without collaterals averaged 88.3 ± 8.6 (SD)% reduction of the internal luminal diameter. Maximal heart rate, workload, exercise duration and the systolic pressure-rate product are presented in Figure 1. Both before and after training there were no significant differences between coronary patients with and without collaterals. After a 6-week training period, significantly higher workloads and exercise duration were tolerated by both groups. No significant changes in the maximal heart rate or the double product were observed at the onset of limiting symptoms.

The incidence of positive (ST segment depression >0.1 mV), negative or questionable results of the exercise ECG in patients with and without collaterals is indicated in Table 2. Before and after training, there was neither a significant difference between the two groups nor a shift in the individual patients.

The results of bicycle ergometry in patients with exercise-induced ischaemic ST segment depression, both before and after physical training, are summarized in

Table 1. Clinical and angiographic data in coronary patients with and without collateral vessels.

	Collaterals (N = 26)	No collaterals (N = 21)
Age (years)	52.5 ± 7.4	53.2 ± 6.3 (2 P = ns)
Men	22	21
Diseased vessel		
LAD	15	9
LCX/RCA	11	12 } (x^2 = 1.02; 2 P = ns)
Grade of obstruction (%)	100	88.3 ± 8.6
Ejection fraction (%)	63.7 ± 8.1	64.0 ± 9.7 (2 P = ns)

Values one means ± SD.

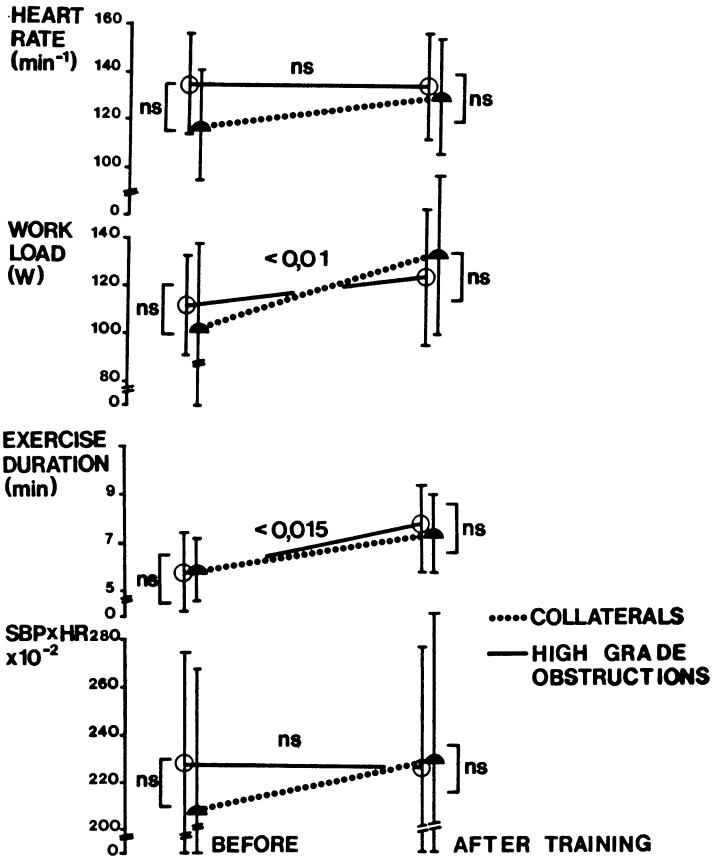

Figure 1. Maximal heart rate, workload, exercise duration, and systolic pressure-rate product before and after training in patients with collaterals and patients with high grade obstruction without collaterals.

Table 2. Results of exercise ECG (bicycle ergometry) in coronary patients with and without collateral vessels.

	Collaterals	No collaterals
Positive	14	12
Negative	7	5
Questionable	5	4

$X^2_{2DF} = 0.07$ (2 P = ns)

Tables 3 and 4. Physical work capacity and exercise duration increased in both groups; this increase was significant only in the group with collateral circulation. Maximal heart rate and systolic pressure-rate product at the onset of ischaemic ST depression were not significantly changed after training in either group. Furthermore, no significant difference between these parameters for the two groups could be demonstrated before and after physical training.

Table 3. Results of bicycle ergometry in patients with and without collaterals *and* positive exercise ECG before and after physical training.

	Collaterals (N = 14)	No collaterals (N = 12)	
Maximal heart rate before training (B/min)	119.6 ± 19.4	133.7 ± 18.3	(2P = ns)
	(2 P = ns)	(2 P = ns)	
Maximal heart rate after training (B/min)	129.9 ± 22.7	135.6 ± 20.4	(2P = ns)
SPRP before training	202.5 ± 40.2	228.9 ± 46.8	(2P = ns)
	(2 P = ns)	(2 P = ns)	
SPRP after training	228.5 ± 53.5	233.6 ± 53.9	(2P = ns)
Age-related maximal heart rate (B/min)	165.9 ± 8.3	166.5 ± 6.5	(2P = ns)

Values are means ± SD. SPRP = Systolic pressure-rate product (mmHg/min/10^2).

Table 4. Results of bicycle ergometry in patients with and without collaterals and positive exercise ECG before and after physical training.

	Collaterals (N = 14)	No collaterals (N = 12)	
Observed PWC before training (Watt)	101.3 ± 34.1	118.3 ± 24.2	(2P = ns)
	(2 P<0.001)	(2 P = ns)	
Observed PWC after training (Watt)	141.1 ± 33.8	132.5 ± 29.6	(2P = ns)
Exercise duration before training (min)	5.79 ± 1.25	6.42 ± 2.31	(2P = ns)
	(2 P<0.001)	(2 P = ns)	
Exercise duration after training (min)	(7.50 ± 1.65)	7.50 ± 1.88	(2P = ns)

Values are means ± SD. PWC = physical work capacity.

Discussion

These results are in agreement with recent experimental and clinical data, and with observations during coronary bypass surgery, indicating a significant reduction in dilatory reserve in post-stenotic areas perfused by subtotally stenosed coronary arteries or by collaterals only. It was suggested that the conductivity of collaterals during maximal vasodilatation corresponds to one-third of the normal coronary conductivity and is equivalent to high-grade stenosis [1, 4, 5, 7, 9, 12]. In our study, global resting ventricular function, haemodynamic data and stress tolerance up to an ischaemic reaction were comparable in patients with one isolated high-grade coronary artery stenosis and in patients with complete obstruction and entire collateral perfusion.

A six-week physical training program had no significant effect on the maximal heart rate and double product at the onset of ischaemic symptoms, indicating no increase in regional oxygen supply by newly developed or functionally improved collateral vessels [6]. Improved exercise capacity and duration in these patients may therefore by attributed to adaptations in the trained skeletal muscles; indeed, the onset of ischaemia in response to a given load was delayed but there was no significant increase in the ischaemic threshold as reflected by the systolic pressure-rate product [3, 10, 11]. This is in agreement with recent data from Schaper [10] who did not find an effect of physical training on collateral resistance in chronic coronary artery occlusion in dogs. In our study, patients with well-developed collateral vessels were untrained before angiography; it therefore seems that the presence or absence of collaterals is primarily determined by the progression and severity of the underlying coronary artery disease.

We can thus conclude that large collaterals show a significant but clearly limited protective effect during stress. A short-term training program did not improve ischaemic threshold in patients with pre-existing collaterals, but did increase exercise capacity, probably a peripheral circulatory effect. Nevertheless, a collateral supply of areas at risk may significantly improve myocardial perfusion compared to a severely stenosed or occluded vessel in the absence of collateral perfusion [2].

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Follow-up study in 25 asymptomatic sportsmen with Wolff-Parkinson-White pattern

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Summary

In order to assess the natural history of asymptomatic Wolff-Parkinson-White (WPW) syndrome, 25 sportsmen aged 27.6 years (range 15–44 years) with a WPW pattern on the ECG have been studied. In all cases, a history was taken, along with a complete physical examination, ECG and M-mode echocardiogram (since 1978) in order to exclude concurrent heart disease. Patients were seen at least once annually at our center. On at least one occasion a maximal exercise tolerance test and a 24-h Holter monitoring were performed, and in 13 subjects, the ajmaline test was carried out.

Mean follow-up is now 9.9 years (range 1–26 years). One subject had a myocardial infarction at age 44 and retired. Holter monitoring detected a single asymptomatic episode of paroxysmal atrial fibrillation with an RR interval of 290 msec in a still-active athlete. No sustained tachyarrhythmia was elicited by maximal exercise testing. We conclude that in this particular self-selected population, the WPW pattern appears to present a benign prognosis, with no greater risk of morbidity than in other asymptomatic groups.

Introduction

Pre-excitation has been considered a potentially dangerous condition due to the risk of arrhythmia and sudden death [1, 4, 5, 9]. A large number of studies are now available enabling us to interpret this condition in terms of morphological and physiological criteria [3, 7]. Most of these studies have been carried out in hospitalized subjects, either symptomatic or with a mix of symptomatic and asymptomatic patients, with or without evidence for arrhythmia. Medical judgement has been supported by this type of evidence.

The increasing number of ECGs taken on a routine basis has led to discovery of an increasing number of asymptomatic subjects, raising problems of counseling about professional activities or sports practice, with implications for medico-legal responsibility. The long-term prognosis for asymptomatic patients is not well-known, and management remains controversial since follow-up studies are still lacking. After extensive review, Ward [7] recommended against granting pilot

licences for solo flying to patients with asymptomatic 'safe' Wolff-Parkinson-White syndrome. Other authors suggest that this condition may have a benign prognosis, and if intermittent, no special management is required [1].

In the Sports Medicine Center of Porto, athletes with Wolff-Parkinson-White syndrome (WPW) in the absence of concurrent heart disease have been allowed to engage in official competition under annual medical control. Data for 25 asymptomatic subjects are here reported.

Methods

Twenty-five asymptomatic athletes aged 26.7 years at the last visit (range 15–44 years), with persistent or intermittent Wolff-Parkinson-White (WPW) pattern defined as a QRS wider than 0.10 sec with a delta wave and PR interval less than 0.12 sec in width, were selected. Isolated short PR and symptomatic subjects (one case) were excluded.

A history, physical examination, standard 12-lead ECG and, since 1978, M-mode echocardiography along with maximal exercise testing and 24-h Holter monitoring were carried out. Concurrent heart disease constituted an exclusion criterion (hypertrophic cardiomyopathy in one case, atrial septal defect in one other).

Exercise testing was performed on an Avionics C16 A treadmill, using the Bruce protocol, or on a Monark cycloergometer with an interrupted protocol of 4 min exercise and 2 min rest (50 Watt incremments), using Mason and Likar monitoring and choosing a lead with a patent delta wave. The theoretical maximal heart rate was defined as (220 minus age) beats/min and has been the goal of the test, unless exhaustion appeared. Attention was given to development of arrhythmias and to QRS normalization patterns.

Random 24-h Holter monitoring was carried out repeatedly, focusing on arrhythmias and intermittency defined as appearance of at least one complex with normal AV conduction in sinus rhythm. An Avionics model 455B recorder and a 655B electrocardioscanner with a model 656 arrhythmia analyzer were used.

Thirteen subjects have been subjected to ajmaline testing, as described by Wellens *et al.* [8]. Fifty mg of ajmaline were injected in during 3 minutes, under continuous ECG control with ECG recordings at least every 30 seconds.

Results

General characteristics

The mean follow-up period was 9.9 years (range 1–26 years). Table 1 shows a general description of the population. Despite careful questioning about palpita-

tions, syncope and sudden weakness, no symptoms were noted. Patient No. 1 had a non-complicated inferior myocardial infarction at age 44, and has retired from official soccer practice (as a referee). He is now doing some jogging, and in December 1984, he performed a normal 12-min Bruce exercise test.

Table 1. General description of subjects.

Case no.	Age	Sport	Intermittency		Holter findings	Exercise test normalization pattern				Exercise findings	Ajmaline normalization	Events	E-up (years)
			ECG	Holter		Abrupt	Gradual		None				
							Total	Partial					
01	44	Soccer/Ref	+	+	0					Init. NL		MI (1980)	26
02	37	Tennis			VPB isol.				+	VPB + APB	No		21
03	37	Soccer/Ref			0	+				APB	No		20
04	36	Soccer			0		+			0	Yes		20
05	35	Basketball	+	+	0					Init. NL			18
06	28	Hockey	+	+	0	+				0	Yes		14
07	30	Soccer	+	+	0					Init. NL			12
08	30	Running			0			+		0			11
09	23	Table tennis			0				+	0			11
10	28	Soccer			0	+				0	Yes		11
11	27	Soccer	+	+	0					Init. NL			11
12	31	Handball			0			+		0			10
13	27	Soccer			PAF	+				0	Yes	PAF	10
14	30	Soccer	+		0	(*)+				0	Yes		8
15	27	Running	+	+	0			+		0	Yes		7
16	33	Handball			0				+	0			7
17	19	Soccer	+	+	APB					Init. NL			6
18	21	Soccer			0				+	0	Yes		4
19	19	Soccer	+	+	0	+				0	Yes		4
20	25	Soccer			0			+		0			4
21	21	Soccer	+	+	APB + VPB isol	+				0	Yes		4
22	21	Soccer	+	+	0	+				0	Yes		3
23	15	Table tennis		+	0				+	0			3
24	20	Soccer		+	0				+	0	Yes		2
25	25	Handball	+	+	VPB isol.					Init. NL			1
Mean	26.7	Total	12	14		7	1	4	7				Mean 9.9

Init. NL = Exercise test initiated with normal AV conduction; MI = myocardial infarction; VPB = Ventricular Premature Beats; APB = Atrial Premature Beats; isol. = isolated; PAF = Paroxysmal Atrial Fibrillation; Soccer/Ref = Formerly football player now Referee; (*) = Non-rate dependent abrupt normalization (recovery).

Holter monitoring

One episode of paroxysmal atrial fibrillation was detected by Holter monitoring in patient no. 13 in 1981, after nocturnal work, during initial sleep at 7:18 a.m. It lasted approximately one hour, and the subject was aware of nothing. During the episode, the minimal RR interval was 290 msec. There had been gradual and complete normalization of the QRS pattern in a previous exercise test, and the ajmaline test showed normalization of AV conduction. Further monitoring, carried out four times, failed to detect any further episodes. The patient is now allowed to play non-professional soccer, and remains asymptomatic.

No episode of paroxysmal supraventricular tachycardia has been detected in any of the patients. Isolated ventricular premature beats graded Lown 2 in case No. 2 and Lown 1 in cases No. 15, 21 and 25 were seen in conjunction with a few premature atrial beats. Intermittency was seen in 14 subjects, 12 of whom showed an intermittent pattern on the standard 12-lead ECG.

Exercise test

Maximal exercise testing failed to provoke sustained atrial tachyarrhythmia in this group. Isolated ventricular premature beats were seen in 2 subjects during maximal exercise (cases No. 2 and 11). AV conduction was normal at the beginning of the exercise test in 6 subjects. There was abrupt normalization, i.e. sudden development of normal AV conduction in seven (37%) of the tests, including one case of abrupt normalization during recovery. There was no normalization in seven others (37%) and in the remaining five tests, there was gradual normalization, total or partial.

Ajmaline test

Thirteen subjects presenting pre-excitation at the time of consultation received an injection of 50 mg ajmaline. Normalization of AV conduction was seen in 11, in seven of whom intermittency had previously been detected on the standard ECG or by Holter monitoring. The other four had a constant pattern, and two of these patients showed no normalization during the maximal stress test (cases No. 18 and 24). Ajmaline failed to restore normal AV conduction in cases No. 2 and 3. Both showed persistent patterns during the exercise test and Holter monitoring. There were no complications with the ajmaline tests.

Discussion

In an athletic population such as we here studied, individuals are self-selected by their predisposition to perform exercise. The prevalence of heart disease is low, and when present it does not impair normal physical performance; complex investigation procedures may thus be poorly accepted by athletes. Nevertheless, it is essential that individual risk be accurately assessed.

In this group of asymptomatic athletes the WPW pattern did not decrease their drive to engage in official athletic competition. The mean follow-up has been 10 years. One subject developed a myocardial infarction, a condition unrelated to the WPW syndrome. The incidence of spontaneous atrial (8%) and ventricular (12%) premature beats detected by standard ECG and Holter monitoring have been similar to other studies carried out in healthy subjects [2]. No paroxysmal supraventricular tachycardia has been identified, and paroxysmal atrial fibrillation (4%) has been found in a proportion lower than reported previously [10]. In this case, the minimal RR interval was 290 msec, widely accepted as a low-risk determinant for ventricular fibrillation [1, 4, 5, 7, 8, 9].

The high proportion of spontaneous and exercise-induced intermittent patterns (68%) probably accounts for the apparently benign course observed in this study.

Intermittency reflects the long refractory period of the abnormal pathway, and some authors recommend that these cases be treated as if no pre-excitation existed [1]. Holter monitoring and maximal exercise testing were useful to define this condition, showing a relatively prolonged refractory period for the anomalous pathway. Non-abrupt normalization and persistent abnormal conduction at maximal exercise output require further investigation for the possibility of accessory pathway block. The ajmaline test could constitute one alternative to invasive procedures [1, 8]; although it has not been practised systematically, this test yielded additional information concerning an accessory pathway block in four cases.

Independently of the systematic approach, even those two subjects who did not show a normalization of AV conduction with ajmaline have been engaged in athletic activity for more than 20 years and are still in official competition. Thus, other properties of the accessory pathway, the atrioventricular nodal pathway, the ventricle [10] or other factors [5] may be involved with an influence on the prognosis. Nevertheless, we believe that the hallmark of potential danger is a short refractory period of the accessory pathway; a workup must be performed to exclude this possibility (Figure 1).

Invasive studies are not always available, and in some instances, have only a limited value [5]. Systematic follow-up studies are thus important in establishing long-term prognosis in this condition.

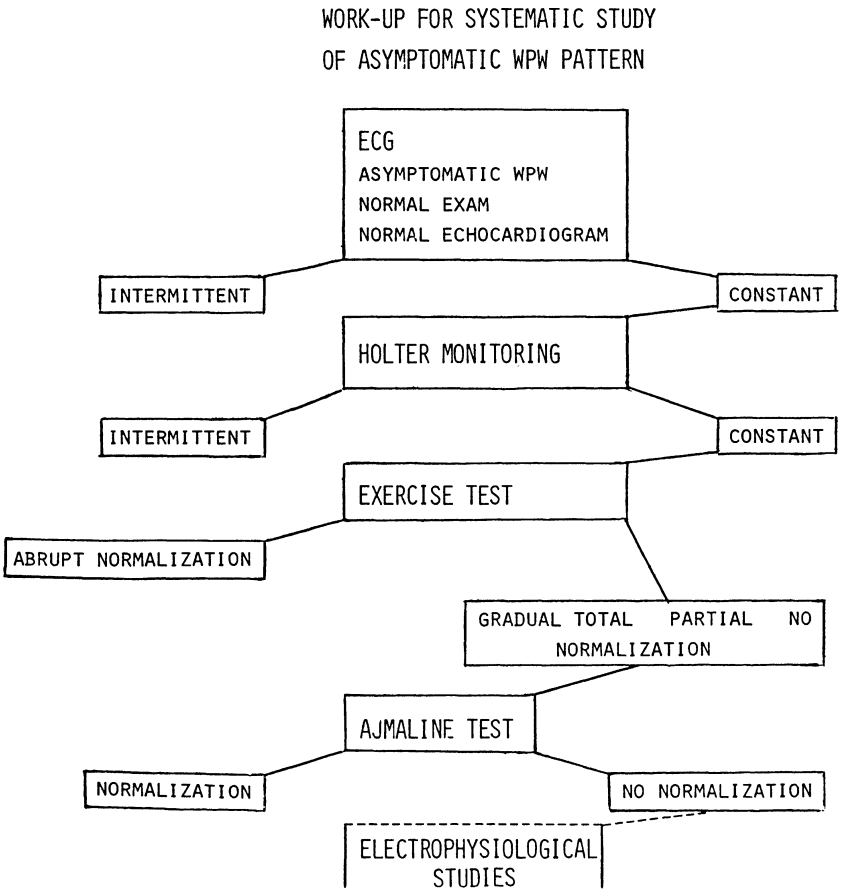

Figure 1. Work-up for systematic study of asymptomatic WPW pattern.

Conclusions

The asymptomatic isolated WPW pattern had a benign course in this group of athletes.

A high proportion of spontaneous or exercise-induced intermittency (68%) has been shown by repeated ECG, Holter and maximal exercise testing. Atrial supraventricular tachyarrhythmias were rare. Paroxysmal atrial tachycardia was not seen, and only one episode of atrial fibrillation has been identified. The ajmaline test has proved to be a safe procedure, providing additional information about the refractory period of the accessory pathway. More follow-up studies are

required to establish individual long-term prognosis of asymptomatic athletes with the WPW syndrome.

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Sports and hypertension

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Summary

Physical training of the hypertensive patient is likely to cause a slight decrease of blood pressure and can therefore be advocated as part of the non-pharmacological management of the patient or as an adjunct to pharmacological treatment. However, because of the possible risks involved, and also to better define the desired training intensity particularly in treated patients, an exercise test is recommended.

The wish to do sports should not influence the general management of the hypertensive patient, but the advice in the young athlete should be well-balanced in order not to impair his performance but also not his health.

Introduction

There are several aspects to the problem of sports and hypertension. One should first determine if physical training is useful in the management of the hypertensive patient. Does sport activity indeed lower blood pressure? One should however consider the possible dangers of physical activity in the patient with hypertension. What is the risk for sudden death? Finally, the problem of the young competitive athlete in whom hypertension is discovered should be addressed.

Training of the hypertensive patient

1. The effect of training on blood pressure

A. Blood pressure at rest

Many studies have evaluated the effect of dynamic physical training on blood pressure in hypertensive patients. Since it is well-known that blood pressure usually decreases on repeated measurement, it is necessary to follow a control group during the same period. Ideally, the control group should be equal to the treatment group in all variables particularly those with potential effect on blood pressure, except for the treatment itself. Some studies did include a control

group, but usually rigid criteria have not been followed; e.g. the controls were not subjected to a low level exercise program. Others followed their patients in a detraining phase. These 'controlled' studies will be summarized first, whereafter the 'non-controlled' studies will be presented for completeness. Studies were selected when the average initial systolic blood pressure was higher than 140 mm Hg [2, 3, 4, 6, 9, 11, 13, 14, 17, 18, 19, 20, 21, 22] or above the 95th percentile in adolescents [8], or when subjects were recruited among borderline hypertensives [5].

a. *Controlled studies*

Table 1 summarizes studies which included a control group [2, 3, 6, 14, 22] or which followed the subjects in a detraining phase [18]. One study [8] used both approaches but details of the control group, in which 'blood pressure did not change', are not reported. Both male and female patients have been studied. The age range was wide. The duration of the training period ranged from 12 weeks to 8 months, with a frequency of about three sessions per week, each lasting from 30 up to 120 min. The dynamic training consisted mainly of bicycling, walking, jogging, running, and calisthenics. The exercise intensity was usually high, between 60 and 90% of maximal work capacity. It can also be seen that the number of observations was sometimes less than the number of patients who entered the study, usually due to drop-outs or to a low adherence rate. The programs resulted in average increases of physical work capacity in the trained group, from 6 to 38%, as judged from estimated or measured maximal oxygen uptake. When measured, no such changes occurred in the control group. Weight decreased significantly in only one study. The majority of observations on blood pressure, either recumbent or sitting, was obtained with a sphygmomanometer. The initial average systolic blood pressure in the various studies ranged from 137 to 182 mm Hg and the diastolic from 78 to 113 mm Hg.

For the control observations changes in blood pressure ranged from +4 to −3 mm Hg (not significant) for systolic and from +3 to −11 mm Hg (significant in two studies [3, 14]) for diastolic blood pressure. In the intervention group systolic blood pressure decreased from −4 to −21 (average: −12) mm Hg and diastolic blood pressure from 0 to −16 (average: −8) mm Hg. Systolic and/or diastolic blood pressure decreased significantly in 5 studies [2, 3, 8, 14, 18], but in two the drop of diastolic blood pressure was also significant in the control group [3, 14]. One study did not find significant changes with training [6] and another did not report levels of significance [22].

b. *Non-controlled studies*

Various studies report on a group of patients who were trained for several weeks, without control group or without a detraining phase [4, 5, 9, 11, 17, 20, 21] (Table 2). Patients were male with a wide age range. The duration of the training period ranged from 4 to 30 weeks, with a training frequency of 2 to 5 times per week.

Table I. Effects of training on blood pressure at rest. Longitudinal controlled studies in hypertensive subjects.

Authors	Characteristics of patients			Training program				Blood pressure (mean ± SE) (mm Hg)								
	Sex	Number entered	Age	Duration (months)	Freq. (per week)	Time	Methods	n	Method	Cond.	Systolic		Diastolic		ΔPWC (%)	ΔWeight	R/
											Pre	Post	Pre	Post			
Barry 1966 [2]	m+f	T. 8	70 (55–78)	3	3×	40′	By, condit., ex.	8	Cuff	Sit	148 ± 7	128 ± 3*	88 ± 4	82 ± 3	$\dot{V}O_2$ + 38%*	NS	–
		C. 5	72 (58–83)	3	–	–	–	5	Cuff	Sit	152 ± 14	156 ± 12	94 ± 6	91 ± 4	?	?	
Schleusing 1968 [22]	?	T. 10	35–45	8	3–4×	60–120′	Walk, jog, by, swim	8	Cuff	?	153 ± ?	145 ± ?	106 ± ?	99 ± ?	$\dot{V}O_2$ + 21%*	?	on R/
		C. 11	?	8	–	–	–	11	Cuff	?	159 ± ?	157 ± ?	105 ± ?	108 ± ?	NS	?	
Bonanno 1974 [3]	m	T. 12	30–58	3	3×	50′	Walk, jog, cal	12	Cuff	Sit	148 ± ?	135 ± ?*	97 ± ?	83 ± ?*	$\dot{V}O_2$ + 6%*	NS	no R/
		C. 12		3	–	–	–	15	Cuff	Sit	150 ± ?	147 ± ?	101 ± ?	90 ± ?*	NS	NS	
Deplaen 1980 [6]	m+f	T. 7	44	3	3×	60′	Walk, jog, cal, by	5	ia	Sit	162 ± 12	158 ± 13	104 ± 6	104 ± 6	$\dot{V}O_2$ + 10%*	NS	only DIU
		C. 8	47	3	–	–	–	4	Cuff	Sup	156 ± 15	154 ± 7	110 ± 11	107 ± 2	NS	NS	
Romàn 1981 [18]	f	T. 30	55 (30–69)	3	3×	30′	Walk, jog, cal...	27	Cuff	Sit	182 ± 3	161 ± 3*	113 ± 2	97 ± 1*	$\dot{V}O_2$ + 24%*	?	no R/
		D.		3	–	–	–	24	Cuff	Sit	179 ± 5		113 ± 2		NS		
Kukkonen 1982 [14]	m	T. 13	42 ± 1 (SE)	4	3×	50′	Walk, jog, by, ski	13	Cuff	Sit	145 ± 4	136 ± 3*	99 ± 1	88 ± 3*	$\dot{V}O_{2est}$ + 10%*	−1.1 kg*	no R/
		C. 12			–	–	–	12	Cuff	Sit	140 ± 3	140 ± 4	97 ± 2	90 ± 2*	NS	NS	
Hagberg 1983 [8]	m+f	T. 25	15.6 ± 0.3 6 (SE)		3×	30–40′	Jog	25	Cuff	Sup	137 ± 1	129 ± 1*	80 ± 2	75 ± 2*	$\dot{V}O_2$ + 10%*	NS	no R/
		D.		9	–	–	–		Cuff	Sup	139 ± 2		78 ± 2		NS		

Abbreviations: Cond.: condition; PWC: physical working capacity; R/: treatment; T.: trained group; C.: control group; Sit: sitting; Sup: supine; NS: not significant; ia: intra-arterial; DIU: diuretics.

Table 2. Effects of training on blood pressure at rest. Longitudinal non-controlled studies.

Authors	Characteristics of patients			Training program				Blood pressure (mean ± SE) (mm Hg)										
	Sex	Number entered	Age	Duration (weeks)	Freq. (per week)	Time	Methods	n	Method	Cond.	Systolic		Diastolic		Mean				
											Pre	Post	Pre	Post	Pre	Post	ΔPWC (%)	Δ Weight	R/
Johnson 1967 [11]	?	4	?	10	3 ×	>35′	Treadmill	4	ia	Sup	188 ± 12	195 ± 7	103 ± 5	105 ± 3	134 ± 9	136 ± 8	↗(%?)	NS	no R/
Rudd 1967 [20]	m	19	48 (40–66)	20	?	60′	Walk, jog, run, swim, cal	19	Autom. device	?	155 ± 3	133 ± 3*	95 ± 2	85 ± 2*	–	–	?	?	?
Boyer 1970 [4]	m	23	49 (42–60)	26	2 ×	45′	Walk, jog, cal	23	Cuff	?	159 ± 4	146 ± 4*	105 ± 1	93 ± 2*	–	–	?	−1.1 kg'	Yes
Hanson 1973 [9]	m	8	42 (30–54)	30	3 ×	60′	Run, cal, sports	5	ia	?	150 ± ?	134 ± ?	86 ± ?	75 ± ?*	109 ± ?	96 ± ?*	$\dot{V}O_2$ + 32%'	?	Yes in 2
Choquette 1973 [5]	m	37	42 ± 7 (SD)	26	2 ×	60′	Cal, jog, volley, swim	37	Cuff	Sit	136 ± 2	122 ± 2*	90 ± 1	82 ± 2*	–	–	PWC_{150} + 18%*	NS	No
Sannerstedt 1973 [21]	m	5	26–38	6	3 ×	60′	Bicycle	5	ia	Sup	–	–	–	–	107 ± ?	105 ± ?	Submax HR −12%	−3.2 kg'	No
Ressl 1977 [17]	m	10	48 (38–53)	4	5 ×	35′	Bicycle	10	ia	Sup	182 ± 5	176 ± 5	99 ± 2	98 ± 1	130 ± 3	129 ± 3	PWC_{130} + 20%*	−3 kg*	No

Abbreviations: see Table 1.

Each session lasted 35–60 min, and consisted of bicycling, walking, jogging, running, etc. Several studies measured blood pressure intra-arterially. The average pre-training systolic blood pressure ranged from 136 to 188 mm Hg (number of studies = 6) and changed by +7 to −22 (average : −11) mm Hg over the training period. Diastolic blood pressure, ranging from 86 to 105 mm Hg (n = 6), changed by +2 to −12 (average : −7) mm Hg. Mean blood pressure, initially 107–134 mm Hg (n = 4), changed by +2, −1, −2 and −13 mm Hg. Systolic, diastolic or mean blood pressure decreased significantly in 4 of the 7 studies. Gains in physical work capacity, if reported, were evidenced by a higher maximal oxygen uptake, a higher work load at a fixed submaximal heart rate or a lower heart rate at a certain work load. Only one study reported a significant change of weight, others reported no change or changes of uncertain statistical significance.

B. Blood pressure during exercise

In five of the controlled studies [2, 6, 14, 18, 22] and five of the non-controlled studies [5, 9, 11, 17, 21] blood pressure was measured at rest and exercise. However in two controlled studies [6, 14] the control group was not studied during exercise, so that, in Table 3, they are mentioned with the non-controlled studies. Blood pressure was reported at variable intensities of exercise. No significant changes occurred in the control group [2, 22] or during detraining [18]. In the trained groups, average pre-training systolic blood pressure ranged from 174 to 226 (n = 9), average diastolic blood pressure from 84 to 119 (n = 9) and mean intra-arterial pressure from 117 to 158 mm Hg (n = 5) at the reported level of physical activity. At an identical level of exercise or at a similar percentage of maximal exercise capacity after training the changes of systolic blood pressure ranged from +17 to −23 (average : −11) mm Hg (significant decrease in 5 out of 9 studies), of diastolic pressure from −5 to −15 (average : −9) mm Hg (significant decrease in 5 of 9) and of mean arterial pressure from −1 to −14 mm Hg (average : −7) (significant decrease in 2 out of 5).

2. Hypertension and exercise-related sudden death

Hypertension is undoubtedly a risk factor for sudden death [12]. The question whether it is also a risk factor for exercise-related sudden death can be addressed by analysing various studies on subjects who died during sport activity [10, 15, 16, 25, 26, 27, 28]. Table 4 shows that exercise-related sudden death occurs almost exclusively in men (which is not only due to greater sport participation), most in their fifth decade, and that ischaemic heart disease was found in approximately 80% of the subjects. Furthermore an effort was made to obtain the risk factor profile of those who died. Hypertension was found in approximately one third of the subjects in whom blood pressure could be traced. This is more than expected

Table 3. Effects of training on blood pressure during exercise. Longitudinal studies

Authors		Level of activity	n	Method	Blood pressure (mean ± SE) (mm Hg)					
					Systolic		Diastolic		Mean	
					Pre	Post	Pre	Post	Pre	Post
Controlled studies										
Barry 1966 [2]	T.	Pretraining work load limit	8	Cuff	191 ± 10	170 ± 13*	84 ± 4	78 ± 4	–	–
	C.		5	Cuff	190 ± 16	194 ± 12	91 ± 11	88 ± 6	–	–
Schleusing 1968 [22]	T.	140 W	8	Cuff	210 ± ?	197 ± ?'	118 ± ?	108 ± ?'	–	–
	C.		11	Cuff	213 ± ?	220 ± ?'	121 ± ?	121 ± ?'	–	–
Roman 1981 [18]	T.	50–70% of $\dot{V}O_2$max	27	Cuff	211 ± 3	196 ± 4*	115 ± 2	105 ± 2*	–	–
	D.		24	Cuff	207 ± 3	–	115 ± 2	–	–	–
Non-controlled studies										
Johnson 1967 [11]	T.	65% of $\dot{V}O_2$max	4	ia	211 ± 3	228 ± 14	119 ± 8	110 ± 6	158 ± 7	154 ± 15
Hanson 1970 [9]	T.	Treadmill walk, 4°	5	ia	202 ± ?	198 ± ?	99 ± ?	87 ± ?*	131 ± ?	118 ± ?
Choquette 1973 [5]	T.	75 W	37	Cuff	174 ± 4	157 ± 4*	95 ± 2	90 ± 2*	–	–
Sannerstedt 1973 [21]	T.	75 W	5	ia	–	–	–	–	117 ± ?	112 ± ?*
Ressl 1977 [17]	T.	100 W	10	ia	226 ± 5	203 ± 6*	113 ± 3	104 ± 2*	154 ± 3	141 ± 3*
Deplaen 1980 [6]	T.	$\dot{V}O_2$ = 1.5 l/min	5	ia	202 ± 10	199 ± 7	106 ± 4	101 ± 4	142 ± 4	141 ± 6
Kukkonen 1982 [14]	T.	HR = 66% of ΔHR	13	Cuff	214 ± 7	195 ± 8*	90 ± 3	75 ± 3*	–	–

in men of similar age. Although such retrospective data are of course open to criticism, they suggest that patients with hypertension run a higher risk of sudden death during exercise, mainly due to coronary heart disease. This should be taken into consideration when counseling the patient with hypertension on physical training.

3. Recommendations

The benefits of increased physical activity for general well-being need not be repeated. The effect on blood pressure however can not be a major argument to promote physical activity in the normotensives because the possible effect is small, if any [7]. In the hypertensives, however, a better blood pressure control can be expected from an increase of physical activity and may therefore be recommended. In mild hypertension it can have a place in the non-pharmacological approach of the patient, together with relaxation therapy and/or a reduction of sodium consumption and calorie intake. In more severe hypertension it can be an adjunct to the pharmacological treatment; several training studies involved treated patients [4, 6, 9, 22]. The general recommendations for the initiation of pharmacological treatment should be followed [29] and blood pressure should be controlled before starting training in patients with definite hypertension.

One should advise dynamic exercise. This consists of rhythmic movements of large muscle groups, as is the case in walking, jogging, cycling, cross-country skiing, swimming and calisthenics. Many authors consider that isometric strength training such as wrestling and weightlifting should be avoided as it may cause a considerable increase in blood pressure during the activity, and the benefits for the hypertensive patients are doubtful [1].

A more detailed analysis of the data [7] also suggests that the blood pressure

Table 4. Hypertension and exercise-related sudden death

Authors	(Ref)	n	Age (years)	Sex (m/f)	IHD (%)	Hypertension	
						(%)	(n/n)*
Opie, 1975	[16]	21	40 (17–58)	21/0	76	20	(2/10)
Thompson, 1979	[25]	18	? (42–59)	17/1	72	31	(4/13)
Walker, 1980	[28]	5	46 (40–53)	5/0	100	40	(2/ 5)
Thompson, 1982	[26]	12	47 (28–74)	12/0	92	0	(0/ 8)
Virmani, 1982	[27]	30	36 (18–57)	30/0	73	46	(11/24)
Jackson, 1983	[10]	9	47 (35–56)	9/0	100	33	(3/ 9)
Northcote, 1984	[15]	30	47 (22–66)	29/1	77	35	(8/23)

* Subjects with hypertension/subjects in whom BP could be traced. Abbreviations: n = number of deaths; IHD = ischamic heart disease.

lowering effect is dependent on the increase of exercise capacity and therefore on the characteristics of the training program. Ideally one should exercise three times a week for 30–60 min and exercise intensity should be at least 60% of the maximal exercise capacity. Since hypertension is a risk factor for cardiovascular disease, an exercise test prior to training is recommended in the hypertensive patient. A graded exercise test until the patient wishes to stop will also allow the determination of the optimal training heart rate in both untreated and treated patients, which is the resting heart rate plus 60% of the difference between peak and resting heart rate. Indeed, antihypertensive treatment, particularly beta-blockers, may affect heart rate.

When there are no signs or symptoms of ischaemic heart disease the patient can exercise on his own; otherwise more intense training should best be started in supervised training programs. Some complications of hypertension such as cardiac failure, renal insufficiency, cerebrovascular accidents, peripheral artery disease, will of course entail specific recommendations on physical activity and rehabilitation, which is beyond the scope of this paper.

Finally the general principles of training should be considered, namely it should be progressive and regular, avoiding exhaustion and sudden bursts of exercise.

The athlete with hypertension

Although rare in the young, hypertension could be a problem for the individual who wishes to excel in competitive sports. When there is no certainty on the necessity of pharmacological treatment, a waiting attitude could be justified because 1. hypertension has not been associated with sudden death in the young athlete and 2. there is no evidence that sport affects the prognosis unfavourably.

Practically [23, 24] one can propose that the diagnosis of hypertension in the athlete justifies a screening investigation including history, physical examination, electrocardiogram, chest X-ray, eye-ground, urine analysis, blood haemoglobin, renal function and serum electrolytes. When after three visits, diastolic blood pressure is less than 95 mm Hg and if neither target organ damage nor an obvious underlying disorder, can be demonstrated, high level sport activity can be allowed without pharmacological treatment provided regular follow-up visits. When diastolic blood pressure remains higher than 95 mm Hg at rest [29], when there is target organ damage, or a probable secondary cause of hypertension, further investigation is advised and treatment indicated. High level sport activity can possibly be allowed when blood pressure is controlled and when it is not precluded or rendered unwise by severe target organ damage or an underlying illness.

Many antihypertensive agents are presently available. With few exceptions every patient's hypertension can be adequately controlled with a minimum of side effects. However exercise capacity can be impaired, either by a direct effect of the

drug or through side-effects. Not all drugs have been tested on their effect on maximal exercise capacity and particularly not on prolonged submaximal performance, but some remarks can be made. Diuretics may affect exercise capacity through changes in circulating volume and electrolyte disturbances. Beta-blocking drugs usually impair exercise performance in the young healthy subject, and these agents could be contra-indicated because of athlete's bradycardia. Among the vasodilators hydralazine and converting enzyme inhibitors have not been shown to cause exercise-related problems; alpha-adrenoceptor blockers might however cause post-exercise hypotension. Slow calcium channel-blockers might become of interest to treat the athlete with hypertension, but more data are needed. Centrally acting antihypertensive agents such as alpha-methyldopa and clonidine may cause drowsiness, fatigue or sleepiness and are therefore not indicated in the athlete.

Because different drugs can affect exercise capacity through different mechanisms it is advisable to test for the most appropriate drug for the individual athlete or to test a combination of drugs in order to achieve an acceptable blood pressure while preserving exercise capacity.

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Exercise and sports in congenital heart disease

L. VAN DER HAUWAERT

Introduction

The vast majority of haemodynamically important congenital heart malformations are nowadays amenable to surgery. Patients with large left-to-right shunts through a ventricular septal defect, patent ductus arteriosus or atrioventricular canal will undergo a corrective operation in the first years of life in order to prevent the development of obstructive pulmonary vascular disease. Because detection is usually later in life and pulmonary hypertension is rather exceptional, atrial septal defect is often corrected at school-going age. Severe pulmonic stenosis and coarctation of the aorta can be successfully relieved at any age, even, if necessary, in early infancy. The two most common cyanotic cardiac malformations need early palliation or correction. In most centres uncomplicated transposition of the great arteries will be functionally corrected by a venous switch operation in the first months of life. Our management of tetralogy of Fallot has dramatically changed during the last decade: few palliative procedures are being performed and they are limited to very young patients in whom the main pulmonary artery is judged to be too small for a safe correction. Although elective surgery may be postponed until late pre-school age (4 to 5 years), the results nowadays are equally satisfying if complete repair is undertaken at a younger age. Most of these operated patients lead normal lifes as adolescents and adults and are able to participate with their peers in sports and physical activities. In some patients, however, the result is not optimal because of residual lesions, impaired myocardial function or surgical trauma to the conduction tissue [8]. Guidelines for operated patients will be discussed in the next paper.

In developed countries, where the facilities of modern cardiovascular surgery are widely available, relatively few adolescents and adults with unoperated congenital heart disease will be seen. Notable exceptions are lesions which are not associated with striking murmurs and therefore remain occasionally unrecognized at routine examinations in childhood e.g. coarctation of the aorta and atrial septal defect. The other unoperated congenital heart defects belong to three major categories 1° minor anomalies with no or minimal haemodynamic repercussion, for which an operation is not indicated e.g. the majority of small ventricular septal defects, slight pulmonic stenosis, 2° anomalies which are well-tolerated in childhood but tend to become progressively more severe during the first decades

of life e.g. aortic stenosis, congenital complete atrioventricular block, 3° serious conditions which are inoperable because of the complexity of the anatomical arrangement or the presence of irreversible pulmonary vascular disease e.g. some extreme forms of tetralogy of Fallot, the Eisenmenger's syndrome.

The purpose of this paper is to present general guidelines for sports and recreational activities in patients with unoperated congenital heart disease and to discuss specific recommendations for a few categories of patients.

General guidelines

Counseling patients with congenital heart disease should be based on

1. A correct diagnostic assessment of the nature and severity of the cardiac anomaly. The cardiologist should therefore be familiar with all aspects of non-invasive cardiac investigation. Recently two-dimensional echocardiography and Doppler-echo studies have considerably improved our ability to diagnose and quantitate structural heart disease. In selected cases, particularly in those considered to be candidates for surgery, cardiac catheterization and angiocardiography are indicated. Up to now an accurate measurement of the pulmonary artery pressure and pulmonary-arteriolar resistance can only be obtained by means of this invasive investigation.
2. A thorough knowledge of the natural history, long-term prognosis and possible complications of the various forms of congenital heart disease.
3. An evaluation of the intensity, metabolic requirements and physiologic effects of recreational activities and sports. The latter aspect will be discussed in some detail.

Recreational activity and sports

The demands placed upon the circulatory system by various activities depend on many factors: the nature of the effort (isometric or isotonic), the duration and intensity of the activity, the environment (e.g. high altitude, temperature), emotional stress, training and conditioning [18]. Sports requiring isometric work e.g. weight lifting, body building, wrestling and some types of gymnastics, may produce a disproportional increase in blood pressure relative to oxygen uptake.

Patients with systemic or pulmonary hypertension or obstructive lesions of the left ventricular outflow, particularly those with congenital aortic stenosis, should therefore be discouraged from taking part in these activities. A classification of sports with respect to exertional intensity and degree of contact (Table 1) gives a rough estimation of energy demands but does not take into account the vigorousness of the movements, the habitual physical activity and degree of training of the

individual patient [18]. For these reasons exercise testing has been advocated and is now widely used to evaluate a patient's functional reserve capacity.

Both the cycle ergometer and treadmill produce adequate and reproducible loads on the oxygen transport system for collecting information about physical work capacity at 170 heart beats/min, total work, endurance time, ventilatory threshold, blood pressure response and electrocardiographic changes [4, 5, 15–19]. We do not systematically use exercise testing in children and adolescents with minor cardiac lesions nor is it indicated in patients with severe pulmonary hypertension or cyanotic heart disease, who always have a very limited exercise tolerance. We found it useful, however, in patients with aortic stenosis, pulmonic stenosis, 'cured' myocardial disease, complete congenital atrioventricular block,

Table 1. Classification of Sports

Primarily isometric
Weight lifting
Wrestling
Water skiing
Archery
Strenuous-contact
Body surfing
Football
Ice hockey
Rugby
Wrestling
Strenuous-limited contact
Basketball
Field hockey
Volleyball
Strenuous-noncontact
Cross-country
Cycling
Gymnastics
Skiing
Swimming
Tennis
Water polo
Moderately strenuous
Archery (isometric)
Badminton
Baseball (limited contact)
Golf
Table tennis
Nonstrenuous
Bowling
Riflery

Modified from Strong and Alpert [18].

dysrhythmias and in patients with residual lesions after corrective surgery. Even in these categories of patients the results should be interpreted with prudence because an exercise test does not mimic the intensity, competition and stimulating ambience which characterize most sports and outdoor activities.

Restrictions

As it is difficult to predict how much energy an individual patient will need to participate, under particular circumstances, in a certain recreational activity, it is virtually impossible to give detailed advice in this respect. Some general guidelines, however, should be explained to the patients, their parents and physical education directors [14, 17].

Normal activity, including school sports, athletics and competition, is advised for the vast majority of children and adolescents with unoperated minor anomalies e.g. the large group of patients with a small ventricular septal defect, small atrial septal defect, trivial pulmonary stenosis or aortic stenosis, slight mitral insufficiency or aortic insufficiency and mitral valve prolapse. Some of these lesions, particularly aortic valve disease, may be progressive over a span of 5 to 10 years and should therefore be re-evaluated at 1- or 2-year intervals. In the past, general practitioners, paediatricians and school physicians were inclined to restrict this category of patients in their physical activity, thereby producing all the physical and psychological ill effects of overprotection, hypoactivity and anxiety [1]. Even children with a normal heart and an innocent (functional) murmur were occasionally discouraged from taking part in sports [2]. At the present time, thanks to the availability of accurate diagnostic tools, there is no longer an excuse for this irrational and invalidating advice.

Mild restriction means that certain types of sports, which require peak efforts of a maximal or near-maximal intensity during more than 30 sec, are to be avoided e.g. sprinting, competition swimming, hockey, football, tennis (single). Peak efforts may indeed generate a rapid increase in pulmonary and systemic pressure or ventricular pressure in case of ventricular outflow obstruction. For the same reason sports requiring a large part of isometric muscle work are not advisable e.g. weight lifting, wrestling, some types of gymnastics, water skiing. School sports are allowed.

Moderate restriction. In addition to the restrictions mentioned above, patients in this category should be advised not to participate in team sports, except baseball and volleyball. When practising individual sports they should be allowed to stop when fatigued. The same rules apply for school sports and gymnastics.

Severe restriction. Only activities that require a low level of energy expenditure are allowed e.g. light calisthenics, walking, cycling on the flat, golf, bowling, table tennis, badminton.

Recommendations for specific defects

The purpose of this section is to outline some recommendations for the more common unoperated congenital cardiac anomalies in adolescence and young adulthood. A summary is found in Table 2, which is based on the Report of the American Heart Association ad hoc Committee on rehabilitation of the young cardiac [14] and the Statement of the Scientific Commission of the International Federation of Sportsmedicine [17].

Ventricular septal defect and atrial septal defect

Defects with a large left-to-right shunt (VSD, ASD, PDA) are surgically closed in infancy or childhood so that patients with this problem are normally not seen as adults. There remains, however, a relativelely large group of patients with a small ventricular septal defect (pulmonary/systemic flow ratio <2 and usually <1.5). These patients present with a loud pansystolic murmur, sometimes accompanied by a thrill, but their electrocardiogram and chest roentgenogram are normal. On

Table 2. Recommendations on recreational activity and sports for patients with congenital heart disease[1]

Defect[2]	Restriction of recreational activity[3]
Aortic stenosis	
mild (gradient <30 mm Hg)	None
moderate (gradient 30–70 mm Hg)	Mild
severe (gradient >70 mm Hg)	Moderate
Atrial septal defect	
with normal pulm. art. press.	None
with pulm. art. hypertension	Moderate
Hypertrophic obstructive cardiomyopathy	Severe
Pulmonary hypertension	
mild (pulm. art. press. <0.5 syst.)	Moderate
severe (pulm. art. press. at syst. level)	Severe
Pulmonary stenosis	
mild (gradient <50 mm Hg)	None
severe (gradient >80 mm Hg)	Mild to Moderate
Ventricular septal defect	
with normal pulm. art. press.	None
with mild to moderate pulm. hypertension	Moderate

[1] Based on the Report of the A.H.A. ad hoc Committee on Rehabilitation of the young cardiac [14].
[2] Only unoperated defects or anomalies which are more commonly seen in adolescence and adulthood are listed.
[3] See text for grading of restrictions.

echocardiograms the cardiac dimensions are also normal. A significant portion of these defects may undergo spontaneous closure, even in adulthood. There is no evidence suggesting that an increase in shunt size occurs over the years. Although one study in adults [7] indicated that the left and right ventricular ejection fraction failed to increase with exercise, maximal endurance time in these patients was found not to be different from that in normal peers [4, 5].

We recently studied a group of 50 children, aged 5 to 18 years (median age 9.7 years), with a small ventricular septal defect (43 patients) or atrial septal defect (7 patients) and found a subnormal $\dot{V}O_2$ at 170 heart beats/min in only 28% [15]. The ventilatory threshold, however, was abnormal in 56% of the patients. This subnormal value was independent from shunt size but correlated significantly with the level of habitual physical activity, which was estimated by a detailed questionnaire. This lack of physical activity in children with minor or hemodynamically unimportant cardiac lesions, may be attributed to an overprotective attitude of the parents and has also been noted in other studies [1, 18, 19]

Patients in this category should be encouraged to take part, without restriction, in normal activities and sports, including competitive athletics.

Isolated pulmonic stenosis

Patients with a systolic pressure gradient <40 mm Hg across the pulmonic valve and/or a right ventricular systolic pressure <60 mm Hg, are usually not operated because the expected long-term course is excellent [12]. In the first decade an increase in right ventricular outflow gradient may occur but later on in life the gradient usually remains stable. Because the peak right ventricular pressure rises only modestly during exercise in patients with mild pulmonic stenosis, they should not be restricted in their physical activity. Mild to moderate restrictions may be indicated in the odd patient, with a gradient >80 mm Hg who, for some reason or another, has not been operated.

Aortic stenosis

The natural history of valvar or subvalvar (discrete) aortic stenosis is usually characterized by a slow deterioration, thickening and fibrosis of the valve and an increase of the obstruction. Aortic valvotomy in childhood does not basically change this evolution and should be considered as a palliative procedure, which is only indicated in severe stenosis with a pressure gradient >70 mm Hg [6].

When advising activities and sports in unoperated patients one should keep in mind that exertion considerably increases the left ventricular peak systolic pressure with a smaller than expected increase in systemic arterial pressure or even a drop in pressure. Exertion may thus provoke myocardial ischaemia and ventricu-

lar arrhythmia [3, 13]. Whitmer *et al.* [20] conducted progressive bicycle exercise tests in 23 children with valvar or subvalvar aortic stenosis: 19 patients developed significant ST depression, some of them with only moderate left ventricular-aortic pressure gradients at rest.

That this group of patients is at risk during physical activity is borne out by the observation that in children aortic stenosis was the most common single cause (18%) of sudden unexpected death from cardiovascular disease, as shown in a cooperative study [9]. Only a minority (10%) of the 254 patients died during strenuous activity. However, half of those who died during or shortly after engaging in strenuous sports had either aortic stenosis or obstructive cardiomyopathy. These disturbing figures should be put into perspective and do not warrant an overrestrictive attitude in the vast majority of patients with mild or moderate aortic stenosis or a bicuspid aortic valve. Indeed, all patients in this cooperative study [9] were symptomatic and had 'evidence of severe obstruction in the form of so-called left ventricular strain pattern in the electrocardiogram or the symptoms of angina or syncope'.

Reasonably safe guidelines for children and adolescents with aortic stenosis can be based on 1° history (symptoms), physical examination and electrocardiogram, 2° non-invasive evaluation of the left ventricular pressure gradient by the echo-Doppler technique, 3° bicycle or treadmill exercise-testing with particular attention to the ST changes and rhythm disturbances [3, 20], 4° if these examinations indicate moderate or severe obstruction cardiac catheterization and direct measurement of the pressure gradient are recommended.

In most cardiac centres patients with a gradient >60–80 mm Hg will be considered candidates for an aortic valvotomy which is a palliative procedure but has a beneficial effect on the myocardial function as it protects the patient against very high peak pressures in the left ventricle [13]. Unoperated patients with congenital aortic stenosis should be mildly or moderately restricted in their physical activity according to the degree of obstruction (Table 2). It is important to discuss at some length specific measures with these patients as they usually have no symptoms and can hardly understand why doctors make a fuss about their condition.

Aortic insufficiency

Aortic insufficiency, either rheumatic or congenital, is rather uncommon in the young. As it is usually well-tolerated, surgery, if indicated, can be postponed until adulthood. In contrast with aortic stenosis, this lesion does not predispose to sudden death. Only patients with severe aortic insufficiency need to be restricted in their activity.

Hypertrophic obstructive cardiomyopathy

The risk of sudden death, probably related to ventricular fibrillation, in youngsters with documented hypertrophic obstructive cardiomyopathy (HOCM) is high [9, 11]. This type of cardiomyopathy was also the most common cause of unsuspected death during or just after exertion in young athletes, in whom the lesion had remained undiagnosed during life [10]. Unfortunately, no clinical or morphologic variable is reliably predictive of sudden death [11]. Regardless of the type of medication (beta-blocking and/or calcium channel-blocking agents) we discourage these patients from participating in most sports and games, particularly those involving isometric work. On the other hand, they are encouraged to practise bowling, golf, cycling on the flat at their own pace or other low-intensity sports, in order to maintain a certain degree of physical fitness.

Severe pulmonary hypertension and Eisenmenger's syndrome

In its broader definition the Eisenmenger's syndrome is characterized by severe pulmonary vascular obstructive disease and a communication (VSD, ASD, PDA, single ventricle, transposition of the great arteries) between the systemic and pulmonary circulation. Frequently the shunt through this communication is bidirectional in earlier life but later becomes predominantly right-to-left, producing central cyanosis. These patients always have symptoms and their exercise tolerance is more or less severely decreased. The condition is inoperable. In a few patients heart-lung transplantation has been successful. There is usually no need to discourage these patients from physical efforts as dyspnoea prevents them from doing anything but the slightest activity. For psychological reasons we therefore take the opposite stand and try to encourage them to go to school as regularly as possible and to join their peers in social activities.

Conclusion

The vast majority of children, adolescents and adults with congenital heart disease should be allowed and even encouraged to participate in physical activities and sports. Lesions that require careful diagnostic assessment and may necessitate restrictions in physical activity include: aortic stenosis, hypertrophic cardiomyopathy and pulmonary hypertension, either primary or secondary to or associated with cardiac malformations.

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The evaluation of exercise performance in children after surgical correction of congenital heart disease

D. MATTHYS and A. DEVLOO-BLANCQUAERT

Summary

In order to advise on recreational and competitive physical activities, children undergoing surgical correction (SC) of congenital heart disease were examined by maximal exercise tests using the Bruce treadmill protocol. 210 patients aged 5–14 years (mean age: 9 years) were studied. Normal values were obtained for 132 normal children of the same age. Maximal endurance time (ET) was used as the criterion of exercise capacity. The heart rate, systemic blood pressure and electrocardiogram were monitored. The mean post-operative ET score was 0.77 standard deviations below the mean for the control group. Arrhythmia occurred in 15% of all the patients but in 36% of the children with tetralogy of Fallot (TOF). Exclusion from competition sports is recommended only in children with TOF, transposition of the great arteries, and aortic coarctation with residual hypertension or associated lesions. Recreational sports are considered to be very important for the physical development of the children in this group. Not only are the others not restricted, they are on the contrary encouraged to participate in athletic activities.

Introduction

The increasing number of children undergoing surgery for congenital heart disease (CHD) creates new problems concerning physical activities [4]. Children with severe heart disease must be excluded from strenuous sports, while on the other hand, children with CHD must participate as much as possible in the activities of children of their own age. The aim of this study was not only to determine objective criteria for preventing exercise-related sudden death in operated children, but also, to reduce unnecessary restrictions from recreational or competitive sports. In addition, there is a lack in objective data concerning exercise testing in young normal children as well as in young heart patients.

Methods

Two hundred and ten children (104 boys and 106 girls) aged 5–14 years (mean age: 9 years) were studied after surgery for CHD. Normal values were obtained from 132 age-matched schoolchildren (70 boys and 62 girls); exercise tests were performed using the Bruce treadmill protocol [1]. This study included only patients undergoing total repair of CHD: palliative and prosthetic valve operations were not considered. The Bruce treadmill test is a continuous graded protocol with step-wise increases in speed and gradient at 3-min intervals from 2.7 to 6.7 km/h and from 10 to 20%. The goal is to reach the level of maximal voluntary effort until the subject is unable to continue. Heart rate, blood pressure and the electrocardiogram are continuously monitored and recorded at the end of each stage, at the end of maximal exercise, and after 1, 2, 4 and 6 min of recovery.

Maximal endurance time (MET) was used as a criterion of exercise capacity. Comparison between children of different ages and either sex was possible by calculating the relative endurance time (RET), relative heart rate (RHR) and relative systolic blood pressure (RSBP), computed by subtracting the predicted from the observed value for each patient and dividing this difference by the standard deviation for that index in the normal group [3].

Results

Exercise performance (Table 1)

While the operated children had a shorter RET than the normal control group, their performance was not very poor. The mean RET of all the patients was

Table 1. The mean relative endurance time (MRET) in children after surgical correction of congenital heart disease.

Defect	Number	MRET	SD	P
VSD	53	−0.76	0.79	<0.001
ASD II	48	−0.45	1.00	<0.01
TOF	33	−0.88	0.92	<0.001
Coarc.	31	−0.82	0.86	<0.001
TGA	16	−1.33	0.92	<0.001
ASD I	11	−1.20	1.02	<0.01
Ductus	10	−0.75	0.59	<0.01
PS	8	−0.49	0.54	<0.05
All	210	−0.77	0.91	<0.001

Abbreviations: see Figure 1.

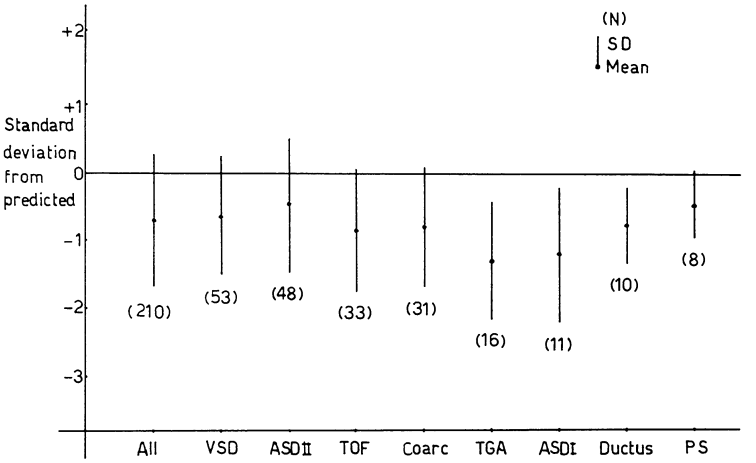

Figure 1. Standard deviations from predicted endurance time (relative endurance time) in all patients and in various subgroups.
Abbreviations: (N) = number of patients; SD = standard deviation; VSD = ventricular septal defect; ASD II = ostium secundum atrial septal defect; TOF = tetralogy of Fallot; Coarc. = coarctation of the aorta; TGA = transposition of the great arteries; ASD I = ostium primum atrial septal defect; Ductus = patent ductus arteriosus; PS = pulmonary stenosis.

0.77 SD below the predicted norm, significantly lower ($p<0.001$) than the control group. The best results were obtained by the ostium secundum atrial septal defect (ASD II), ventricular septal defect (VSD), pulmonary stenosis (PS), patent ductus arteriosus (ductus), followed by the coarctation of the aorta (Coarc.) and tetralogy of Fallot (TDF) groups. The worst results were from patients with ostium primum atrial septal defect (ASD I) and transposition of the great arteries (TGA). These data are plotted out in Figure 1. Table 2 shows the percentage

Table 2. Standard deviation range from predicted endurance time (percent of patients).

Defect	Number	−4	−3	−2	−1	0	+1	+2	+3
VSD	53	0	5	24	47	19	4	0	
ASD II	48	2	4	23	48	19	2	2	
TOF	33	0	15	21	45	18	0	0	
Coarc.	31	3	3	38	38	16	0	0	
TGA	16	6	12	37	37	6	0	0	
ASD I	11	0	18	36	36	9	0	0	
Ductus	10	0	10	10	70	10	0	0	
PS	8	0	0	12	75	12	0	0	
All	210	1.4	7.6	26	46	16	1.4	0.5	

Abbreviations: see Figure 1.

distribution of the patients according to the range of the standard deviation from the predicted endurance time. Almost half of the patients (46%) had an RET between 0 and −1 SD from the predicted normal value and in about one-quarter (26%), the performance was poor (between −1 and −2 SD). Almost one heart patient out of ten had a very low exercise capacity (<−2 SD), four times more frequent than the 2.5% expected in a normal population. 18% of the children had a positive RET, i.e. their performance was better than the mean of the control group of the same age. Here too, ASD II and VSD showed the best scores, with ASD I and TGA showing the worst. About one out of six patients in the TOF, TGA and ASD I group had a very low exercise capacity (<−2 SD).

Heart rate

At rest the heart rate of the patients was somewhat slower than the normals (MRHR -0.31 ± 1.27 SD; $p<0.001$). At stages 2 and 3, the submaximal level, the MRHR of the patients was identical to the heart rate of the normals, however at maximal output, heart patients did not reach pulse rates as high as the control group. This is probably the result of the shorter MET. It is interesting to note that at the submaximal level, most common in daily life, the mean heart rate of the operated patients was the same as the normals.

Systolic blood pressure

There was no difference between heart patients and normals at rest and at submaximal exercise. Somewhat unexpectedly, there was a higher systolic blood pressure at the maximal level in the heart patients than in the normals. The difference was only 0.52 SD, but was statistically significant ($p<0.001$).

Arrhythmia

Exercise-induced arrhythmia occurred mainly in patients with TOF. 36% had ventricular or supraventricular ectopic beats versus only 15% in the entire group of operated patients.

The detection of arrhythmias in patients with TOF after surgical correction is extremely important. Ventricular ectopic beats at exercise may not only be associated with sudden death, but are also related to abnormal haemodynamic status and are an indication for further invasive investigations. In this study four patients had the combination of premature ventricular or atrial contractions with an increase in J point depression at maximal exercise. All of them showed a very low RET, with cardiomegaly on chest films and elevated right ventricular pres-

sures in post-operative catheterization. One died suddenly, two required re-operation for right ventricular outflow tract obstruction or aneurysmal dilatation of the pericardial patch. The fourth will be reinvestigated in the coming weeks.

Discussion

This paper describes the application of the Bruce treadmill protocol for exercise testing in children after surgical correction of congenital heart disease, and confirms its suitability for the examination of children aged 5 years and older [1].

There is a lack of information concerning non-invasive exercise testing in young operated heart patients. The majority of studies have dealt with older patients [7] or with subgroups such as TOF [6, 9, 10] and coarctation of the aorta [5] where specific topics (arrhythmia, blood pressure profile) are considered. In some studies, the operated patients were only a minority [2]. The present data demonstrate that exercise testing provides important information regarding desirability of different degrees of physical activity in children after surgical correction of CHD [8].

In conclusion, after a normal exercise test, we recommend no restrictions in recreational or competitive sports in children operated upon for VSD, ASD, patent ductus arteriosus and coarctation of the aorta with normal blood pressure profile and without associated lesions. Only recreational activities are authorized in children with TGA, TOF and coarctation with severe residual hypertension or associated lesions.

Children operated upon for congenital heart disease must be encouraged to participate in athletic activities, competitive or recreational, according to the authorized level.

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CHAPTER IV

EXERCISE AND SUDDEN DEATH

Sudden death and sports

J. POOL

Introduction

Sudden death represents a paradoxical situation. Obviously healthy people, participating in activities which are believed to be healthful, die, probably due to these activities.

From a Public Health point of view three questions arise: 'What is the scope of the problem?', 'Do sporting activities increase risk?' and 'What are the determinants of sports-related death?'

Scope of the problem

The number of deaths occurring during sporting activities has been published from at least 3 countries: West Germany, with a population of about 61 million inhabitants reports 139 cases per year [9, 10]. Finland, 4.8 million inhabitants, 48 cases per year [22]. The Netherlands, 14.6 million inhabitants, 104 cases per year [2]. The number reported from Germany is probably underestimated since the authors used insurance statistics. The other authors tried to assess all deaths by questionnaires to physicians and/or by the national death registers. This means that the size of the problem is rather small. In the Netherlands 25,000 men under the age of 65 die each year from myocardial infarction while 1,450 die in traffic accidents.

Thompson *et al.* [20] calculated the risk of death during running and jogging in Rhode Island, U.S.A. He estimated one death per 7,620 athletes per year or one death per 400,000 running hours in men between the age of 30 and 64. In the Netherlands Pool *et al.* [16] calculated for all sports one death per 20,000 athletes per year, or one death per four million sporting hours in men between the age of 12 and 73.

Do sporting activities increase the risk?

Although the risk per sporting hour is low, it is increased compared to other activities. Some authors expressed the risk of sudden death during exercise as the

ratio of the actual risk to the expected risk. The expected incidence was derived from published mortality tables presuming an equal distribution of mortality over the hours involved (Table 1). The difference can be explained by different age and different physical activity. Moreover Pool *et al.* [16] included all deaths in the numerator and in the denominator, while Thompson *et al.* [20] and Siscovick *et al.* [18] calculated cardiac deaths only. The data of Siscovick *et al.* are of interest. The relative risk is five in people who are used to vigorous exercise and 55 in people who are used to work of low intensity only. These figures do not mean that people engaged in sporting activities have an increased risk. On the contrary, from several studies it is known that the total risk of people who are physically active is lower than average [8, 14, 15, 17]. But when they die, they die 'on the battlefield'.

What are the determinants of sports-related death?

The difference between the sexes is striking. In all published studies the number of female victims is low, varying from zero to ten percent of the total deaths [6, 12, 13, 16, 19, 20, 21, 22]. This sex difference can not be explained by a difference in participation in sporting activities or by a difference in cardiac mortality only. Pool *et al.* [16] reported 13 female victims out of 188 (7%). In the Netherlands the exposure of women to sporting activities is about 70% of that of men. The cardiac mortality is about 10 years behind, so the expected number of sports-related deaths would be much higher than the observed 13. As Haskell [4] suggests possibly the intensity of sporting activities is of importance also.

The relative risk increases with age (Table 2), based on the data of Pool *et al.* [16]. Only in the oldest age group is the relative risk lower again, possibly due to a less accurate estimate of sporting activities in this age and of a positive selection of old men still active in sports.

Risk factors are reported in some studies (Table 3). Smoking is seen quite frequently, more than expected in people active in sports. A high percentage of smokers was also reported in a survey of young athletes in the Netherlands [1]. Except for the small study of Thompson *et al.* [19] hypertension was seen more frequently than in the general population.

Table 1. (Cardiac) death during exercise in men.

	Activity	Age	RR
Pool *et al.* [16] (All deaths)	All sports	12–73	1.8
Thompson *et al.* [20]	Jogging/running	30–64	7
Siscovick *et al.* [18]	Vigorous exercise	20–75	5–55

RR = Relative Risk = Actual Risk/Expected Risk.

Pre-existing heart disease was reported by Dolmans *et al.* [3] in over 50% of the victims. This included myocardial infarction, angina pectoris, cardiomyopathy, myocarditis, valvular heart disease and rhythm and conduction disturbances. Many of these were known to the treating general practitioner. In this study 16% of the victims had consulted a cardiologist or internist in the two years preceding the accident because of cardiac symptoms. Prodromal symptoms were reported in 40 to 70% of the cases [3, 12, 19], similar to data of the WHO in the general population [24].

Autopsy findings in the larger series published are presented in Table 4. In older people coronary atherosclerotic heart disease was seen in most patients. In the young victims cardiomyopathy and other heart disease, such as valvular heart disease, myocarditis, myocardial fibrosis, left ventricular hypertrophy and abnormal coronary arteries were found. Other significant findings were rupture of the aorta, intracranial haemorrhage and leukaemia. The 'diagnosis' no abnormal findings is dependent on the accuracy of the autopsy e.g. whether the conduction system of the heart has been analysed completely.

Many studies are limited to one sport, such as running and jogging [5, 11, 19, 20, 23] and squash [12]. The absolute number of victims in different kinds of sport in different countries is probably related to the number of participants. In the USA [7] the majority of the (young) athletes died playing basketball and football. In

Table 2. Incidence (males per year) related to age. [16]

Age	N	Athletes per death ($\times 10^3$)	Sporting hours per death ($\times 10^6$)	RR
12–24	11	85	20	0.6
25–34	20	40	4	2.7
35–49	41	8.3	1.2	3.6
50–75	22	12	1.6	1.5

RR = Relative Risk = Actual Risk/Expected Risk.

Table 3. Risk factors and death during sporting activities.

	N	Smoking (%)	Hypertension (%)
Thompson *et al.* [19]	18	15	– 30
Thompson *et al.* [20]	12	55	0
Dolmans [2]	188	52 (45)*	29 (13)**
Northcote *et al.* [12]	30	40	35

* Dutch athletes 18–35 yrs.
** Dutch population >20 yrs.

Finland [22] most athletes died skiing and running. In The Netherlands [16] most victims were found playing soccer as shown in Table 5. In this table also the number of deaths per 100,000 participants are presented. A rather high risk is seen in tennis and jogging and a very low risk in leisure sports like walking, swimming and sailing. Probably these different risks are due to the age of the participants and the intensity of these activities.

Conclusions

Death, directly related to sporting activities is rare. The total risk is low, but the relative risk is increased during vigorous exercise. In women the risk is extremely low. Risk increases with age and with the intensity of exercise.

Pre-existing heart disease and cardiovascular risk factors are frequently present. At necropsy in victims over 35 years coronary heart disease is the most frequent finding. In young victims cardiomyopathy is found often.

Patients with cardiovascular disease should be advised on prodromal symptoms and on the risk of vigorous exercise.

Table 4. Autopsy findings.

	Thompson *et al.* [19]	Maron *et al.* [7]	Dolmans *et al.* [3]		Northcote *et al.* [12]
Age	42–59	13–30	12–35	36–71	22–66
N	18	29	29	24	–31
CAHD	13 (72%)	3 (10%)	5 (17%)	18 (75%)	23 (74%)
Cardiomyopathy	–	14 (48%)	7 (24%)	4 (17%)	1 (3%)
Other heart disease	3 (17%)	9 (31%)	7 (24%)	2 (8%)	4 (13%)
Other significant disease	–	2 (7%)	5 (17%)	–	1 (3%)
No abnormal findings	2 (11%)	1 (3%)	5 (17%)	–	2 (6%)

CAHD = Coronary Atherosclerotic Heart Disease.

Table 5. Deaths and sports [16].

	Number of deaths	Deaths per 100.000 athletes
Soccer	49 (24)*	2.6
Tennis	17 (16)	3.2
Other ball games	28 (14)	1.6
Jogging	27 (20)	4.3
Leisure sport	25 (15)	0.4

* ( ) >35 years.

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Sudden death and vigorous exercise

R. NORTHCOTE

Summary

The circumstances surrounding 60 sudden deaths (59 men, one woman) associated with squash playing are described. The subjects had a mean age of 45.6 years with a range of 22–66 years. Necropsy reports were available in 51. The certified cause of death was coronary heart disease (CHD) in 51 cases, valvular heart disease in 4 cases, cardiac arrhythmia in 2 cases, hypertrophic obstructive cardiomyopathy in one case, with only two non-cardiac causes. Forty-five reported prodromal symptoms, the most common of which was chest pain and 22 had at least one medical condition related to the cardiovascular system during life, the most common of which was hypertension (14 subjects). Those dying from CHD had a high frequency of CHD risk factors.

It is possible that some of these deaths may have been detected by prospective medical screening and appropriate counseling which would have detected most of the patients with overt cardiovascular disease and some of those with subclinical CHD.

Introduction

Squash is a sport which has had a global increase in popularity and has become particularly popular in the United Kingdom with middle-aged executive males. It is a game played in an enclosed court similar to raquet ball, which is played in the USA. The Squash Rackets Association have crudely estimated that there may be 2.5 million people in the United Kingdom playing squash once a month or more, and competitions have recently been expanded to include veteran and even vintage groups. Therefore a growing number of high-risk individuals are being exposed to the potential hazards of a physically exhausting sport. Sudden death in sport is a recently recognized phenomenon for which little scientific information exists. Most previous investigation on sudden death in sport has concentrated on running [31–33] and track and field sports [18, 21, 27], and these reports have recently been reviewed by ourselves [24]. We have previously reported also the findings of 30 deaths associated with squash [25]. Following this study we have continued to collate information on sudden death in squash players and this report concerns the results of investigation of 60 such deaths.

Subjects and methods

Sudden death associated with sport or vigorous exercise is normally categorized only according to the medical cause of death. Thus, it is not usually possible to obtain information on such cases from Government Authorities. We were able to collate a series of 89 sudden deaths associated with squash occurring between October 1976 and February 1984 by a retrospective examination of media reports and by a prospective mail survey of sports centres and squash clubs throughout the United Kingdom. The Squash Rackets Association (SRA) assisted us with a number of cases, and a few were notified directly to us by witnesses or by officials of individual squash clubs. In 60 cases we were able to obtain sufficient information to investigate the death in detail. In each of these cases the next of kin (usually the spouse) was interviewed with a standard questionnaire, to establish the circumstances surrounding the sudden death and the presence of premorbid symptoms or CHD risk factors, as defined by Kannel *et al.* [12]. Prodromal symptoms were defined as any change from usual health status considered important by the subject and reported to relatives or friends within one week of death [1]. Next of kin were invited to provide a crude assessment of the level of fitness and personality characteristics of the deceased subject. Permission was sought to approach witnesses to the event and the family physician. In addition, if the subject had undergone a medical examination for the purposes of employment or life insurance, we asked permission to approach the appropriate authority for the results. Necropsy findings (if available) were reviewed and the results of any Coroners enquiry (England) or Procurator Fiscal investigation (Scotland) were taken into account.

A diagnosis of CHD was made if necropsy evidence of severe or pronounced coronary atherosclerosis was present, as judged by the Pathologist, or when the lumen had narrowed by more than 70%, with or without evidence of fresh thrombus, in the absence of other pathology. Pathological evidence of a healed myocardial infarction supported a diagnosis of CHD.

Results

Sixty cases of sudden death associated with squash were identified. All occurred in the United Kingdom between May 1976 and April 1984. Only one female death was recorded and all subjects were white. Their mean age was 45.6 ± 10.3 (SD) years with an age range of 22–66 years. The distribution of ages is represented in Figure 1. Sudden death has been defined as death occurring within 1–24 hours of the onset of symptons [7, 14]. In this study, all subjects collapsed while playing squash or in the following hour, and with one exception all subjects died within one hour of play. The remaining subject died in hospital six hours later. With the exception of this case the onset of symptoms was rapid, and culminated in

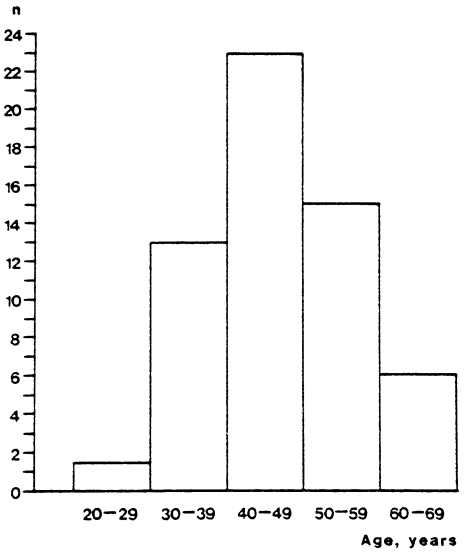

Figure 1. Age distribution of sudden deaths associated with squash (N = 60).

collapse of the subject and unconsciousness. Forty-six subjects collapsed on the squash court – 10 of these in the first 10 min from commencement of activity (mean of 22.6 ± 12 min into play) and 14 collapsed in the first hour after play. Nine of these subjects collapsed in the first 10 min post-exercise. Four subjects collapsed while taking a hot shower. Death was virtually instantaneous in 59 cases – the remaining subject collapsed 60 min after play, while driving, and died 6 hours later in hospital. Cardiopulmonary resuscitation (CPR) was attempted in 46 cases – usually by onlookers, many of whom were physicians, nurses or first-aid personnel.

All the subjects had been playing squash for at least one year (mean 11.6; range 1–40 years). In 9 subjects, an accurate estimation of the frequency of participation could not be determined. Of the remainder, forty-eight players visited the court on a mean of 2.3 times a week (range 0.25–7) to play squash and the duration of play was usually 40–60 min in each case. One subject had, on medical advice, not played squash for five years until his death, another played only when on vacation and one subject (aged 60 years) had recently started playing with his son after a 10 year break following medical advice to retire from the game. Sixteen subjects began playing squash over the age of 40, while only 17 had been playing before the age of 30 years.

Cause of death

The probable causes of death are summarized in Table 1. Necropsy reports were available in 51 cases. CHD was confirmed as the cause of death in 42 cases, with severe or pronounced stenosis of at least one main coronary artery. In 35 cases dying of CHD a detailed description of the state of the coronary arteries was available from the necropsy report.

Although 18 subjects had pathological evidence of a healed myocardial infarction, this had been diagnosed in only two cases during life. In a further two cases, however, there had been clear symptoms of prolonged anterior chest pain 10 days and four months prior to death respectively. In both of these cases the pathological appearances were compatible with a myocardial infarction at these times.

The most frequently isolated artery affected by atherosclerosis was the left anterior descending coronary artery with severe triple-vessel disease found in 12 cases. Fresh thrombus was found to occlude a coronary artery in 9. In one (aged 22 years) the left main stem coronary artery was completely occluded by fresh thrombus in the absence of significant coronary atheroma.

Valvular heart disease was responsible for death in four cases and had been documented during life in all four, but none had been advised against physically exhausting sporting activity. One subject (aged 26 years) had a congenitally stenotic bicuspid aortic valve which was found to be accompanied by concentric left ventricular hypertrophy and irregular thickening of the valve cusps and distortion of the commissures at necropsy examination. Another subject had congenital prolapse of the mitral valve with atrial fibrillation during life – this abnormality was confirmed at necropsy and was accompanied by pronounced left ventricular hypertrophy (heart weight – 550 g) in the absence of significant CHD. The cause of death was certified as acute heart failure, possibly in association with a cardiac arrhythmia [22]. Mitral stenosis resulting in acute heart failure was found in the third subject in the absence of significant CHD. The fourth subject had a calcified aortic valve, resulting in severe aortic stenosis, and calcified coronary arteries. However, the certifying pathologist judged that the aortic valve lesion was the principal cause of death.

Table 1. Probable cause of death in squash players (N = 60).

Cause	N
Coronary heart disease	51
Valvular heart disease	4
Cardiac arrhythmia	2
Non-cardiac	2
H.O.C.M.*	1

* H.O.C.M.: hypertrophic obstructive cardiomyopathy.

In one subject, hypertrophic obstructive cardiomyopathy, a disorder known to be associated with sudden death during strenuous exercise [20], was found in the absence of other pathology. This 37-year old man was not known to his family physician, but his annual medical examinations at work had detected no abnormality. Only two non-cardiac causes of death were found. In one a right intracranial haemorrhage occurred, symptoms developing 60 min after playing squash. This subject died in hospital six hours later without regaining consciousness. The other had played squash very soon after a heavy meal and was found at autopsy to have aspirated stomach contents with resultant collapse of both lungs. There was no evidence of cardiac pathology in either case. In two cases, no pathological abnormality was found at necropsy and in both the certifying pathologist judged that death resulted from a cardiac arrhythmia. This diagnosis should preferably be supported by a thorough histopathological examination of the conduction system of the heart [10]. This was carried out in a specialist centre in one case, but no abnormality was detected. Since both deaths were instantaneous, it seems likely that the certified cause of death was correct.

Of the 9 remaining subjects who did not undergo necropsy examination all were certified to have died as a result of CHD. In five of these cases there were no clearly distinguishable features apart from the sudden collapse to support a diagnosis of CHD. One subject gave a classical history of cardiac pain to his physician in the 30 min prior to his death accompanied by sweating suggesting that CHD was the likely cause of death. Two subjects gave a history of previous myocardial infarction and one of these had also had documented aortic regurgitation in the 10 years prior to death. A further subject gave a history of angina pectoris one year before death and had significant ST segment depression on exercise electrocardiography.

Pre-morbid conditions and symptoms

Forty-five subjects had reported at least one prodromal symptom within one week of their sudden death, sixteen subjects had reported more than one symptom (Table 2). Only 9 were known to have consulted their family physician about these symptoms although a further two had arranged appointments with their practitioner.

Twenty-two subjects were known to have had at least one medical disorder related to the cardiovascular system during life: 14 had hypertension documented on two or more occasions. However, only two subjects had received antihypertensive medication. Excluding hypertension, 14 subjects had medical conditions known to themselves and their family physician, relevant to the cardiovascular system (Table 3).

Of the 51 subjects dying of CHD, 32 had at least one CHD risk factor, 15 had two and 5 had three or more (Table 4).

Perception of physical fitness

Next of kin were requested to assess the physical fitness of the deceased in relation to the general population in five categories ranging from very fit to very unfit. No subject was considered unfit or very unfit, while 32 of the group were considered to be very fit, 22 fit and only 6 were considered to be of average fitness.

Personality and psychological influences

Despite a high prevalence of prodromal symptoms and known medical conditions, these subjects ignored these factors to play squash. Next of kin were asked to describe the deceased's predominant personality characteristics. Twelve subjects were considered to be competitive, ambitious, hard driving and perfectionist individuals, 13 were thought to be very aggressive, two to be very competitive and one to be obsessive about fitness. One subject was described as eccentric and only four were thought to be passive. In 27 no clearly recognizable traits could be identified.

Psychological or emotional stress might have contributed to death in four cases. The most overt instance concerned a man of 26 years with a congenitally stenotic aortic valve who collapsed and died, minutes after assaulting his opponent on the squash court and causing a fractured mandible.

Table 2. Prodromal symptoms.

Symptom	N
Chest pain/angina	15[a]
Increasing fatigue	12
Indigestion/heartburn/gastrointestinal symptoms	10
Excessive breathlessness	6[b]
Ear or neck pain	5
Vague malaise	5
Upper respiratory tract infection	4
Dizziness/palpitations	3
Severe headache	2[c]
None	5

[a] One subject, an international squash player, had recently consulted a physician because of chest pain following squash play.

[b] One subject, who ran one mile every morning, had extreme breathlessness on three successive mornings before he died, but was not deterred from further strenuous exertion.

[c] Cause of death in one subject was intracranial haemorrhage.

Occupation

There was a high proportion of professional individuals in this sample, including 14 company directors, nine subjects working in higher education (including two University Professors and seven lecturers), four civil servants, one physician, four engineers, and one school teacher. The remainder worked in a variety of other occupations only two of which could be considered non-sedentary.

Table 3. Clinical and demographic findings in subjects known to have medical conditions.

Subject	Age	Years playing squash	Frequency maches/week	Clinical diagnosis	Symptoms	Risk factors	Cardiac pathology
D.J.	52	5	1	Previous (2×); MODM	Nocturnal angina	D	Healed MI; R + L. CA Occlusions
G.T.	69	35	2	IHD; Previous CABG; Internal pacemaker	General malaise	S	Healed MI; 3-vessel diseases
B.L.	26	3	1	AS	Flu-like symtoms 1 week	–	Bicuspid AV; Concentric LV; Hypertrophy
B.E.	65	35	1st match in 5 years	Previous MI	Fatigue	S/H	N/A
M.W.	44	3	2–4	IHD	Angina pectoris	S/FH	3-Vessel disease; Thrombus occluding RCA
J.B.	51	25	3–4	Atypical chest pain	Chest pain	FH	Healed MI; 3-Vessel disease
J.R.	43	2	2	Gastritis	Dyspepsia; chest pain; malaise	–	MI aged n 10 days; LV hypertrophy; 3-Vessel disease
R.S.B.	62	30	3	AF	Previous collapse at squash; Malaise	–	Healed MI; 3-Vessel disease
P.J.	39	10	7	SAH 17 yrs	–	S	LAD occlusion
J.G.	54	2	1–2	IHD	Angina pectoris	S/HL	N/A
J.B.	66	Return after 10 years lay-off	1–2	AF; MVP	Dyspnoea	FH/M	MVP; large dilated heart (wt. = 550 gms)
J.M.	32	6	1	Previous MI; AI	–	3	–
R.F.	45	12	3–4	MS	–	FH	LV hypertrophy; severe MS; moderate CHD
D.J.	52	4	3	Previous MI (2×) MODM	–	S/H/D	–

Abbreviations: AF = atrial fibrillation; AI = aortic incompetence; AS = aortic stenosis; AV = aortic valve; CA = coronary artery; CABG = coronary artery by-pass graft; D = diabetes; FH = family history; H = hypertension; HL = hyperlipidaemia; IHD = ischaemic heart disease; L = left; LAD left anterior descending coronary artery; LV = left ventricle; MI = myocardial infarction; MODM = maturity onset diabetes mellitus; MVP = mitral valve prolapse; MS = mitral stenosis; N/A = not available; R = right; S = smoking; SAH = sub-arachnoid haemorrhage.

Table 4. CHD risk factors in subjects dying of CHD. (N = 51).

Risk factor	N
Smoking (>10 cigarettes/day)	25
Family history of early MI (<55 years)	18
Hypertension	14
Angina/previous MI	8
Hypercholesterolaemia	3
Diabetes mellitus	2

CHD = coronary heart disease; MI = myocardial infarction.

Discussion

These data confirm that CHD is responsible for most cases of sudden death associated with vigorous sport. In the age group of subjects concerned the results are in agreement with other studies which have examined sudden death in sport [18, 27, 31–33]. In particular, a recent study of 30 deaths in joggers [32] reported a similar prevalence of CHD and autopsy evidence of healed or acute myocardial infarction (MI). This report also remarked on the high frequency of CHD risk factors in their group. Another study of nine joggers demonstrated a high frequency of pre-morbid cardiovascular conditions [9] (i.e. previous MI, angina, hypertension, diabetes), in keeping with our results, and the authors suggested that the deaths may have been prevented had the subjects participated in less strenuous exercise. In our study 22 subjects had medical conditions relevant to the cardiovascular system, but only two subjects had been advised against further participation in squash by their physician. Valvular heart disease was responsible for four deaths in this study, and may have contributed to one other (certified cause of death CHD), who was also known to have aortic regurgitation. None of these subjects were advised against strenuous sport despite the fact that the lesions were recognized by physicians during life. Hypertrophic obstructive cardiomyopathy may be responsible for about half the sudden deaths in a youthful athletic population during sport [19], but we were able to identify only one case (aged 38 years). One of our subjects played squash 30 min after a heavy meal and was found to have aspiration collapse of both lungs from bulky undigested food particles. This would indicate the necessity of undertaking such activity at least two hours after eating to allow for adequate digestion. Less common causes of sudden death during physical activity have been described, including myocarditis [2] and fibromuscular dysplasia of the sinus or atrioventricular node artery [10]. Such abnormalities could conceivably be missed during routine autopsy examination [30]. In two of our cases no gross pathological abnormality was found to explain the sudden death, one of these underwent detailed histopathologic examination at a special centre, with no abnormality discovered. The cause of

death in these cases is a matter for speculation, although a cardiac arrhythmia seems the most likely cause of death.

In this study the most frequent pathological lesion was severe stenosis of at least one major coronary artery, with fresh occlusive thrombus present in only 18% of cases. A recent study of 100 sudden cardiac deaths by Davis and Thomas [5], showed that 44% of cases had major fresh thrombus occluding more than 50% of cross-sectional area of the coronary vessels. The descrepancy with our study may be due to the possibility of thrombi going undetected during the Coroners routine autopsy as opposed to a prospective detailed study of coronary vasculature. Alternatively, it is possible that coronary artery occlusion can occur without thrombus formation during vigorous exercise, perhaps by the mechanism of coronary artery spasm.

Essentially, sudden cardiac death is due to ventricular fibrillation or asystole. Such an event may be more likely during vigorous exercise in subjects with CHD, as oxygen demand may outstrip the ability of the coronary arteries to supply it. In addition it is also possible that metabolic influences associated with exercise may precipitate or contribute to an arrhythmia. For example, free fatty acid and catecholamine levels may rise during exercise [11] and can cause arrhythmias [15] and arterial thrombosis [8] especially in the presence of coronary artery stenosis [28]. These changes, together with exercise-induced lactic acidosis [3], and hyperkalaemia [16] may also help to explain the fact that although cardiopulmonary resuscitation was performed in 46 cases no success was recorded. In general, these metabolic changes make resuscitation following cardiac arrest less likely to be successful. In this study we were impressed by the large number of cases in which CPR had been attempted by trained personnel, and it leads us to suspect that there is an underestimation of the frequency of cardiac events during squash, as we have no data on survivors.

It is not possible from these data to determine whether the subjects would have survived had they not exercised. However, we suspect that even if MI were to have occurred, sudden death is more likely during vigorous exercise. This suggestion is supported by the Framingham study [13] and by a British report examining the circumstances of 100 sudden deaths due to CHD [23]. Friedman *et al.* [7] found that individuals dying instantly, as in this study, were significantly more likely to be engaging in severe or moderate exertion just before death and usually had severe CHD, precipitating cardiac arrhythmias. We have previously demonstrated that squash is capable of raising heart rate to 90% of predicted maximum for extended periods of time and to generate significant cardiac arrhythmias in a young normal population [26], this would suggest that it may be an inappropriate sport for those with CHD or other cardiac disease or even those in the coronary-prone age group.

A large number of individuals in this study with known medical conditions continued to play squash. There seems to be a general unwillingness of men in middle-age to admit that they are in poor physical condition and/or health. They

are still tempted to perform feats more appropriate to a younger, fitter individual – often with disastrous consequences. Both ourselves [25] and others [27, 31] have noted that sportsmen tend to deny physical infirmity and prodromal symptoms and this was confirmed in this study with 22 subjects known to suffer a cardiovascular condition and 75% admitting to at least one prodromal symptom. Apparently, there is reluctance to seek medical advice over such symptoms, which may be regarded as insignificant by some individuals. There is also an apparent inability on the part of these individuals to recognize the gravity of these symptoms and ignorance on the part of physicians who apparently condone vigorous, physically exhausting exercise in the face of cardiovascular disease. An overzealous approach to exercise is potentially dangerous to certain individuals characterized by some of the cases outlined in this report.

At least half of the subjects in this series may have been Type A personalities, which may alone contribute to sudden death and the development of CHD [14, 29], in addition to their tendency to ignore prodromal symptoms and conditions. In four cases acute psychological stress may have been implicated in the sudden death, which both Engel [6] and Lown [17] believe can precipitate lethal cardiac arrhythmias. The mechanism in which type A behaviour contributes to sudden death is unknown – increased secretion of adrenalin and nonadrenalin has been recorded in Type A males carrying out a stressful task [34]. This suggests hyperresponsiveness to environmental stress – such stress may be evident in the enclosed, competitive environment in which squash is played.

It would appear, that although there is a statistically small risk of sudden death during squash, there is an appreciable mortality associated with the game, which is probably not shared by other sports – this might reflect the numbers playing the game, but could equally reflect the strenuous and demanding nature of the game which is clearly unsuitable for those with cardiovascular disease. Likewise, the preponderance of males in this study may reflect the greater number of males/females playing in the coronary prone age group or could reflect the increased frequency of CHD in the former.

Rather than damaging the game of squash, our objective is to draw attention to areas which will improve its safety and enjoyment of playing, and we would congratulate the SRA for recognizing this problem by forming a medical study group in 1980 to monitor the situation, and for circulating a list of precautions to prospective players in all their affiliated clubs.

We would hope that reports such as this will lead to a greater awareness of the dangers of such exhausting, inappropriate exercise in both the public and in the medical profession.

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