AGARDograph No. 210
on
Treadmill Exercise Testing at the USAF School of Aerospace Medicine: Physiological Responses in Aircrewmen and the Detection of Latent Coronary Artery Disease
by
V.F. Froelicher, F. Yanowitz, A.J. Thompson and M.C. Lancaster
TREADMILL EXERCISE TESTING AT THE USAF SCHOOL OF AEROSPACE MEDICINE: PHYSIOLOGICAL RESPONSES IN AIRCREWMEN AND THE DETECTION OF LATENT CORONARY ARTERY DISEASE

by

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This AGARDograph was sponsored by the Aerospace Medical Panel of AGARD.
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Published May 1975
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613.69:613.7:616.1:611.1

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London. W1P 1HD
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Section I

INTRODUCTION

Coronary heart disease (CHD) has reached epidemic proportions in all of the developed countries of the world. The United States is second only to Finland in the incidence of CHD. In fact, CHD accounts for over 1,000,000 deaths in the United States each year, which is more than all other diseases combined. Over 265,000 of these deaths occur in individuals under 65 years of age. Over half of these deaths are unexpected in that they occur without preceding symptoms of CHD. Despite the selective nature of the USAF flying population, CHD is the leading disease cause of death, disability and removal from flying duties. It appears that USAF aircrewmen very well fit the national statistics. Because of the critical nature of flying duties and the pertinence of flying safety, the early detection of CHD is nowhere more essential than in the USAF flying population.

The purpose of this monograph is to present the experience of the United States Air Force School of Aerospace Medicine (USAFSAM) in the use of treadmill exercise for evaluating asymptomatic aircrewmen. The monograph consists of separate studies involving different aspects of treadmill testing experience at the USAFSAM including descriptions of techniques used at the USAFSAM.

Section II

PHYSIOLOGICAL PARAMETERS OF EXERCISE PERFORMANCE

The initial efforts in cardiovascular evaluation were oriented to the measurement of performance parameters. In 1920, the Schneider test was developed. This consisted of walking up five steps 14 inches high and back down in 15 seconds with measurements made of the pulse and blood pressure response. In his initial work with an exercise stress test, Master used a set of two nine-inch steps and related the amount of exercise to age, heart rate response and heart rate recovery at two minutes postexercise. From these studies, Master derived a set of tables based on age and weight that indicated the number of trips a normal individual could make across the steps in one and one-half minutes and still have a return of heart rate to the baseline value within two minutes. It was not until 1941, that the ECG response to the Master's test was considered and experience began to be collected regarding the meaning of ECG changes for the diagnosis of CHD.

Essentially, these early tests depended upon the response of heart rate and blood pressure after exercise to evaluate the functional capacity of the cardiovascular system. When the technology became available to collect and analyze expired air, the measurement of maximal oxygen consumption (VO₂ max) was considered advantageous in evaluating functional capacity. In fact, tests were specifically designed to measure this physiological parameter. Some of the different types of tests utilized and their comparative performance will be discussed later.

Maximal aerobic working capacity is defined as the work level at which oxygen consumed fails to increase linearly with further increases in workload and the oxygen consumption at this point is called VO₂ max. VO₂ max is dependent upon many factors, but it is considered the best index of work capacity and maximal cardiovascular function. However, there are many factors that influence this parameter, including:

1. genetic endowments;
2. hemoglobin and hematocrit levels as well as blood volume;
3. level of physical training (including type and intensity of training, and the age it occurred);
4. bed rest;
5. age and sex;
6. ambient and body temperature;
7. general health as well as the integrity of the cardiovascular and cardiopulmonary systems; and,
8. oxygen tension of the inspired air.

These factors have been reviewed in detail in extensive review articles. The following discussion will touch on some aspects of the factors influencing VO₂ max.

1.) The cardiopulmonary system and VO₂ max

The ability of the cardiopulmonary system to forward oxygen from the surrounding atmosphere to the mitochondria of the cells, the site of oxidative metabolism, is determined by a series of interrelated and interdependent systems. At rest and in the absence of pathology, considerable reserve is present in each of these systems. The factors which limit the maximum capability of oxygen transport, as measured by the VO₂ max, have not been well defined and may in fact have considerable variability. Basically there are two convective systems, the pulmonary ventilation and circulation, and two diffusing systems, the alveolo-capillary and capillary-tissue cell interfaces. Both the size and functional capacity of these systems need to be considered in any discussion of the determination of maximum oxygen transport.
Pulmonary ventilation could limit VO_2 max by virtue of the size of the lungs. Vital capacity (VC), total lung capacity (TLC), or functional residual capacity (FRC) could limit VO_2 max. Also, from a functional standpoint, maximum voluntary ventilation (MVV), diffusing capacity (D_50) or flow rates such as maximum expiratory flow (VEF max) could limit VO_2 max. Holmgren\(^{14}\) has shown that the work of breathing at a heart rate of 170 beats per minute \( (W_{170}) \) is highly correlated with VO_2 max, VC, MVV, the expiratory volume of the forced expiration (FEV max), carbon expired volume \( (V_{co} \max) \), and to the D_50. It has however been assumed that the limitation of VO_2 max is not based upon the capability to move air maximally since MVV is always greater than the volume of air exchanged at maximal exercise \( (VE_j) \). This is not necessarily a valid conclusion. Healthy subjects may reach VEF max over a considerable part of the \( V_j \) at heavy but less than maximal work.\(^{15-17}\) Once VEF max is reached, further attempts to increase flow could only increase the work of breathing and not the \( V_j \). Also, Shepherd\(^{18}\) has demonstrated that for a ventilatory span from 90 to 130 liters per minute, there is a small oxygen cost of only 1 ml of ventilatory volume. However, the useful limit of ventilation (the point where cost exceeds income) was reached at approximately 120 liters per minute. This was felt to be due to a dramatic drop in arterial blood pressure when ventilation exceeded 90 liters per minute Thus, it could be possible to reach maximum ventilatory capacity during heavy exercise at exchange volumes less than predicted from the resting 15 second MVV test. Also, the workload of breathing could become significant and reduce useful work capacity. This probably varies between individuals. In conclusion, although more investigations are required regarding this subject, ventilation could be a limiting factor in exercise, particularly in fit subjects.

The circulatory system could be a limiting factor on VO_2 max in the same fashion as pulmonary ventilation. The size of the various components such as blood volume, total hemoglobin, oxygen concentration, oxygen saturation, ventilation, arterial oxygen saturation, cardiac output, central blood volume, and arterial pressure may all affect oxygen transport capacity. It is obvious that the size of the normally functioning heart is related to the stroke volume. Since oxygen transport is chemically dependent upon hemoglobin, the amount of hemoglobin present, its concentration, and its affinity for oxygen, can place limiting factors upon VO_2 max. While HR max is relatively stable for a given individual \( (C.V. = 1-2\%) \), there is considerable variation on an inter-individual basis \( (S.D. = 10-12 \text{ beats/min.}) \) as well as a decline with age.\(^{17,14}\). Cardiac output \( (CO) \) is the product of HR \( \times SV \). Heart rate does not encroach upon ventricular filling to a significant degree until heart rates of 180 or greater are reached. At this point, there is a diminution from the expected theoretical rise in \( C.O. \), which again varies somewhat with the filling pressure. Central blood volume is a key factor in the filling pressure and orthostatic blood shifts cause changes in the available central blood volume. Central blood volume is obviously related to the venous system and therefore to body position and external pressure. Central blood volume during exercise may be augmented by shifts from the splanchic circulation as has been shown by Rowell, et al.\(^{27}\). In their study, the estimated hepatic and splanchic blood flow decreased in proportion to the intensity of exercise, falling to 20% of the resting value as VO_2 max was approached.

The alveolo-capillary diffusing system has been studied from the standpoint of being a limiting factor on maximal exercise. In 1919, Harrop\(^{26}\) reported that exhausting exercise could reduce the oxygen saturation of arterial blood to 85%. Later investigators observed an increase in VO_2 max at what was judged to be exhausting exercise by supplementing the oxygen content of the inspired air during exercise.\(^{29-31}\) Bannister and Cunningham\(^{32}\) found an increase in work capacity during exhausting exercise by increasing the inspired oxygen content by supplementing the ambient air with 100% oxygen. On the other hand, Mitchell, et al.\(^{33}\) found no significant change in arterio-venous oxygen saturation from resting values of 97.1% ± 3.1 as compared to maximal exercise values of 94.7% ± 2.6. In a group of 4 young sedentary individuals, Rowell, et al.\(^{27}\) found the oxygen saturation in arterial blood to be 95.8% at rest and 93.4% during exhausting exercise. After a 3-month period of intensive conditioning for middle distance running the values were similarly 95.4% at rest and 91.4% during exhausting exercise. Comparison with 4 trained endurance athletes showed a interesting drop in arterial oxygen concentration and ventricular volume. Central blood volume during exercise may be augmented by shifts from the splanchic circulation as has been shown by Rowell, et al.\(^{27}\). In their study, the estimated hepatic and splanchic blood flow decreased in proportion to the intensity of exercise, falling to 20% of the resting value as VO_2 max was approached.

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cardiac outputs as high as 40 liters per minute have been measured in some endurance athletes. With these high cardiac outputs, there would be an inadequate amount of time during which the red cell would be exposed to the pulmonary capillaries. This would be another explanation why the arterial oxygen saturation might drop at high levels of exercise in well-trained athletes as Howell has found.

2.) Physical training and \( V\text{O}_2\) max

Problems develop when attempts are made to compare the "fitness" of different populations, using \( V\text{O}_2\) max. Considerable interindividual variation is present which is additionally affected by age, sex, heredity, body build, lean body mass (LBM), types of exercise habits, type of test used, and method of measuring \( V\text{O}_2\) max. Astrand has demonstrated that in subjects 50 to 54 years of age, the \( V\text{O}_2\) max was 62%, in subjects 55 to 59 years of age was 59% and in subjects 60 to 64 years of age was 52% of the value predicted from the nomogram of Astrand and Ryhming which was derived from young subjects. This same decline in \( V\text{O}_2\) max with increasing age has been demonstrated by Julius, et al, who also showed a comparable decrease in cardiac output with age and a lower maximal heart rate. In prepubertal girls, the maximum oxygen intake per kilogram is closely comparable to that of boys. Deterioration, however, begins at puberty and this has been noted to be more marked in North America than in the Scandinavian countries. The difference in \( V\text{O}_2\) max between teenage boys and prepubertal girls in Scandinavia may be small enough to be attributable to differences in proportion of body fat; however, this is not true in North America. Women show less change with aging than do men in adult life. The type of exercise test used affects the values obtained for \( V\text{O}_2\) max. Astrand and Saltin have shown that the highest \( V\text{O}_2\) could be obtained from running up hill. In comparison, cycling was slightly lower, supine cycling gave a 15% lower \( V\text{O}_2\) and a similar reduction was demonstrated for swimming. Maximum work with the arms gave an oxygen uptake that was about 70% of the \( V\text{O}_2\) max when cycling. Ishiko showed the importance of type specific exercise habits while testing response to exercise in Japanese Olympic team members. He also demonstrated the necessity for consideration of other variables when assessing performance. How to relate \( V\text{O}_2\) max to body fat and LBM is uncertain. Buskirk and Taylor have shown the \( V\text{O}_2\) max to be closely correlated with active tissue derived from LBM minus bone mass. They have also shown that athletes have a higher \( V\text{O}_2\) max per kilogram of active tissue than untrained subjects indicating that their oxygen transport system and muscular system were both quantitatively and qualitatively superior. Bradley, in a study in which 6 young subjects were conditioned, reported that while all of the body weight loss could be accounted for on the basis of loss of body fat without a concomitant increase in non-fat body mass, there was a significant increase in the \( V\text{O}_2\) max suggesting that there was a change in energetic mechanisms rather than a simple increase in the bulk of metabolizing tissue. Along with this must be considered inborn ability or the hereditary limits, both in regard to type and amount of work capability. The highest recorded \( V\text{O}_2\) max is 85 cc's per kilogram per minute (Jim Ryan, U.S. Olympic Miler) and yet the son of the great distance runner Lash, who disliked and avoided physical exercise, had a measured \( V\text{O}_2\) max of 75 cc's per kilogram per minute. Holmgren has stated "the degree of fitness is not expressed by a single measurement of maximum oxygen uptake or by the rate of work at a heart rate of 170 beats per minute." He suggests that only by expressing the \( V\text{O}_2\) max as a fraction of the \( V\text{O}_2\) max capability at peak training would \( V\text{O}_2\) max have relative dimension. The implication from this is obvious. In order to assess the fitness of a population based upon \( V\text{O}_2\) max, one must know what this population could attain in the way of \( V\text{O}_2\) max with intensive physical conditioning. Even so, task specific performance cannot be equated to \( V\text{O}_2\) max. Predictions of fitness based on aerobic capacity are accurate for a homogeneous sample to separate those who are physically trained from the strictly sedentary, but not accurate in heterogeneous samples since such factors as health, cardiovascular integrity, strength, environmental stress, motivation, and anaerobic capacity are not considered. Machado stated "the item which best correlates with the ability to shovel coal over extended periods is the ability to shovel coal over extended periods." Any evaluation of fitness of a population or of a training program must include an evaluation of "fitness for what?"

Despite the rather large number of unanswered questions which together make a definition of physical fitness difficult, if not impossible, there are many reasons why we should know the levels of fitness in different population groups and in specific situations. Despite its limitations, \( V\text{O}_2\) max is currently considered to be the best single measurement of fitness. Extrapolation from an extensive literature suggests that a level of approximately 40-45 cc \( O_2/Kg/min \) should be the arbitrary minimum level of fitness for adult males up to the age of 60.

3.) Disease and \( V\text{O}_2\) max

Other difficulties arise when attempting to assess the meaning of \( V\text{O}_2\) max. It may be "normal" in the presence of diseases, such as hypertension, mild anemia, diabetes, cancer and in patients who have definite atherosclerotic heart disease. This occurs especially in those who maintain an exercise program. In addition, some individuals may reach a high level of \( V\text{O}_2\) max but demonstrate disturbing ST segment depression on their electrocardiograms, arrhythmias, or blood pressure elevations. These findings are not uncommon in the population of apparently healthy subjects seen at the USAP School of Aerospace Medicine. The need for a thorough physical evaluation and correlation of other parameters of clinical diagnostic usefulness with the \( V\text{O}_2\) max seems self-evident. We must consider all of the factors that play a part in determining \( V\text{O}_2\) max in order for this measurement to have any clinical value.
4. Methods of measuring VO\textsubscript{2} max

Treadmill exercise testing is currently the most commonly used clinical method of evaluating an individual's functional capacity in the United States while bicycle ergometry is more popular in European countries. Gas measurement techniques are used in conjunction with the test to determine VO\textsubscript{2} max. Maximal oxygen consumption can be used clinically to estimate the performance of the heart pump. Since maximal A-V O\textsubscript{2} difference does not differ much under similar circumstances, maximal oxygen consumption is linearly related to maximal cardiac output.\textsuperscript{33}

The first treadmill exercise protocols for measuring maximal oxygen consumption were designed for healthy subjects and consisted of intermittent progressive workloads, often separated by days. The lengthy separation was considered to be necessary since near maximal work was fatiguing and could influence subsequent efforts. These treadmill protocols were designed to achieve a workload at which there would be no increase in oxygen consumption from a previous workload of lower intensity. This plateau value was considered to be the maximal oxygen consumption. Taylor and colleagues reported the reproducibility and the factors affecting maximal oxygen consumption using their interrupted protocol (figure 1).\textsuperscript{44,45}

The interrupted test extending over multiple days is inconvenient and often impractical. Subsequent work by Mitchell, et al\textsuperscript{46} presented results using a modification of the Taylor protocol with workload stages separated by ten minutes rather than by days. Mitchell, et al, demonstrated reproducibility of maximal oxygen consumption measurement comparable to the original Taylor protocol. However, the very strenuous nature of this test makes it poorly suited for routine clinical application.

Subsequently, other investigators designed more convenient exercise protocols which were more applicable to clinical utilization. The Balke-Ware treadmill protocol utilized a constant treadmill speed of 3.3 mph (90 meters/min) with a 1% rise in grade per minute and was designed to evaluate physical fitness\textsuperscript{47} (figure 2). Bruce, et al, have used a continuous protocol increasing the speed and grade every three minutes (figure 3).\textsuperscript{48} In an effort to isolate the cardiovascular influence on maximal oxygen consumption, they have classified individuals as sedentary or active by their exercise habit history.\textsuperscript{49}

Section II

B

A COMPARISON OF TREADMILL EXERCISE PROTOCOLS

Numerous treadmill exercise protocols are in use in the United States today, but the majority are modifications of the Taylor, Balke or Bruce protocols. A study was designed to compare VO\textsubscript{2} max and other physiological parameters measured during these three standard protocols and to evaluate the reproducibility of each. This study has been presented in detail elsewhere.\textsuperscript{50,51}

METHODS

Fifteen volunteers were screened for entry into the study on the basis of normal physical examination, medical history, pulmonary function, ECG, double Master's test, chest x-ray, hemoglobin and hematocrit. The subjects lived at home and went about their usual routines. They kept their physical activity and weight stable during the nine weeks of the study.
The standard Bruce and Balke protocols were studied. The Taylor protocol was modified by having five-minute rest periods between exercise stages. Each subject performed one exercise test per week for nine weeks. The nine weeks were divided into three periods, each consisting of three weeks. During each period, the three different protocols were performed in individually randomized order. The tests were performed on approximately the same day each week and at the same time for each individual. Subjects fasted for at least four hours prior to each test and exercised only if they felt well. Expired air was collected using a mouthpiece and nose clip, Koegle’s valve, and neoprene balloons.

RESULTS

No statistical difference was detected between the three protocols or the three periods for maximal heart rate. Also, no difference was detected in \( \text{VO}_2 \) between the periods; however, there was a statistically significant difference \((p < .001)\) between the three protocols (Table 1). The greatest mean maximal oxygen consumption was obtained using the modified Taylor protocol. The mean maximal oxygen consumption using the Bruce and Balke protocols was 6.5% and 9.7% less respectively than that obtained with the modified Taylor protocol.

| Table 1. Mean maximal HR and \( \text{VO}_2 \) for all periods with \( \pm \) one standard deviation |
|----------------|----------------|
| Protocol      | HR max         | \( \text{VO}_2 \) |
| Bruce         | 185 ± 14       | 44.3 ± 6.0     |
| Taylor        | 187 ± 13       | 47.4 ± 6.2     |
| Balke         | 184 ± 15       | 42.8 ± 6.0     |

There was no statistical evidence of variability differences in \( \text{VO}_2 \) or in HR max among the three protocols. This suggests that the measurement of maximal oxygen consumption is equally reproducible by the three protocols and comparable HR max can be obtained.

The mean maximal treadmill time with standard deviation in minutes for the 15 subjects is shown in Table 2. There is a statistical difference \((p < .001)\) in maximal treadmill time between periods for the Bruce and Balke protocols and also for the modified Taylor protocol \((p < .01)\). The mean maximal exercise time increases in spite of no difference in mean maximal oxygen consumption between periods. Also, the Balke protocol takes longer to perform than the Bruce protocol.

The relationship of maximal oxygen consumption and maximal treadmill time for each subject in each of the three periods is illustrated graphically in Figure 4. The relationship of maximal treadmill time to maximal oxygen consumption is inconsistent even within a single period, but it is especially inconsistent when considering the periods together.

The mean heart rates and oxygen consumptions at the submaximal points were analyzed for each of the three protocols as shown in Tables 3 through 5. There was generally a statistical difference \((P=.05 \text{ or less})\) between period one and period three with the exception of oxygen consumption in the Taylor protocol. A decline in heart rate and oxygen consumption at most submaximal workloads was demonstrated. The increase in maximal treadmill time without an increase in maximal oxygen consumption was possibly due to this improvement in submaximal mechanical efficiency. Generally, no statistical difference was found for the ventilatory equivalent between periods at these submaximal points; therefore changes in respiratory efficiency were probably not involved.

DISCUSSION

This study allows comparison of data obtained using the Balke exercise protocol which has been used extensively at the USAFAM with data obtained using the Bruce or Taylor protocols with regard to physiologic parameters of physical performance.

No significant difference was found in the mean maximal heart rates obtained in the three treadmill protocols. However, the modified Taylor protocol yielded a higher mean maximal oxygen consumption than either the Bruce or Balke protocols. This difference is important in comparing studies of maximal oxygen consumptions using different protocols.

Statistical analyses showed no significant difference in the reproducibility of the measurement of maximal oxygen consumption between the three protocols. However, the coefficient of variation for the Balke protocol was greater suggesting that a similar study with a larger number of subjects might demonstrate a significant difference between the protocols. This would be consistent with the influence of factors other than maximal oxygen consumption, such as muscle glycogen stores, on prolonged exercise.\(^{(54)}\)

The increase in mean maximal treadmill time with treadmill experience was consistent with the findings of other investigators.\(^{(49,55)}\) The decrease in submaximal oxygen consumption and heart rate for similar workloads could have accounted for the increase in performance time. However,
variation in anaerobic debt or lessening of anxiety with treadmill experience could be other explana-
tions for the increase in performance time. Physical conditioning was not involved since there was no statistical difference in the mean maximal oxygen consumption between periods.

A wide range of maximal oxygen consumption was found for any particular maximal treadmill time. This was especially apparent when the data from all periods were considered, but the relationship was even poor when the data from only one period were considered. Although differences in submaxi-
mal mechanical efficiency between individuals or particular groups could not be demonstrated in this study, there most likely are individual differences during maximal exercise. This could be one explanation for the poor relationship between maximal treadmill time and maximal oxygen consumption.

The decrease in submaximal oxygen consumption and heart rate for similar workloads from period one to period three has been described by other investigators who have performed sequential exercise studies and this phenomenon has been called habituation.(56-58) Mechanical efficiency of walking must be involved, possibly through changes in stride length.(59) This phenomenon must be taken into account when studying the mechanical efficiency of treadmill performance and in the use of sequential submaximal heart rate limited tests.
Section II

C

THE PREDICTION OF MAXIMAL OXYGEN CONSUMPTION FROM MAXIMAL TREADMILL TIME USING THE BALKE TREADMILL PROTOCOL

As previously discussed, physical training and cardiovascular function are two of the factors that affect maximal oxygen consumption.\(^{(7,8)}\) Balke attempted to evaluate the degree of physical fitness by testing only healthy men, while Bruce has attempted to isolate cardiovascular functional performance by classifying men as sedentary or active by an activity questionnaire.\(^{(48,49,60)}\) Both Balke and Bruce have proposed nomograms for estimating maximal oxygen consumption from maximal treadmill time. These nomograms are for the practical application of treadmill testing in situations where the equipment for expired air analysis is not available. Bruce's nomograms are designed to determine the "functional aerobic impairment" of individuals by adjusting for age. The clinical usage of such nomograms is dependent upon how well maximal oxygen consumption can be estimated by maximal treadmill time. The following is a review of a study conducted in this laboratory to test the hypothesis that an individual's maximal oxygen consumption can be realistically estimated from a continuous progressive treadmill protocol. This study has been reported elsewhere.\(^{(61)}\)

METHODS

Treadmill testing was performed in the morning with subjects fasting. This was their first experience at treadmill walking. They were not allowed to support their weight on the handrails. Treadmill speed was constant at 3.3 mph (90 m/min) and the grade was increased 1% every minute. The ECG was monitored continuously during exercise and for eight minutes postexercise. The subjects were urged to give a maximal effort. However, during the first quarter of the study, arbitrary heart rate limits of 200 and 180 were inconsistently imposed for the special project candidates and the normal consultation patients respectively. Thereafter, no heart rate limits were imposed. The treadmill used had a grade limit of 22%, so data from 55 men who exceeded 22 minutes of treadmill walking were considered separately.

Expired air was collected using a standard mouthpiece and nose clip, Koegle's valves and turret\(^{(53)}\) and neoprene balloons during the final minute of exercise. Gas volume measurements were made using a Tissot correcting for pressure and temperature. Carbon dioxide and oxygen content was measured using a Beckman LD-1 and Beckman E-2 gas analyzers which were calibrated daily with gases analyzed with the Micro-Scholander technique. One hundred and three randomly selected samples of expired air were evaluated simultaneously using the Beckman instruments and the Micro-Scholander technique to check for accuracy.

The data collected on 1800 USAF aircrewmen consecutively studied at the USAFSAM were reviewed. Men with any of the following findings were excluded from further analysis: (1) symptoms or findings of cardiovascular disease or any ailment that could limit treadmill performance; (2) a submaximal treadmill effort as judged by those monitoring the tests and by review of the data, including a maximal respiratory quotient (RQ) less than one; (3) resting ECG abnormalities such as bundle branch blocks, repolarization abnormalities and abnormal Q waves; (4) resting blood pressures consistently above 140/90 as well as labile hypertensives; and (5) abnormal ECG responses to maximal treadmill testing or a double Master's test.

One thousand and eighty men remained who were judged to be free of systemic and cardiovascular disease after a thorough medical and cardiovascular work-up. Thirty percent of these men were referred for evaluation as special project candidates, 15% for ophthalmological and otolaryngological problems, 14% for syncope or near syncope, 10% for neurological evaluation, 9% for psychiatric problems, and the remaining 22% for minor medical problems or to rule out erroneous diagnoses. The age range was from 20 to 53 years.

A special subset of 127 additional men were studied in order to check the air collection technique and to analyze the oxygen consumption and heart rate approaching maximum. No heart rate limits were set and multiple full minute bags of expired air were collected prior to maximum. Their data were considered separately.

RESULTS

Balke's nomogram was constructed with data from subjects who exercised to a heart rate limit of 180; therefore our study group was divided into two subgroups. One subgroup included only those who exercised to a heart rate of 180 or less, while the other consisted of those who exercised to higher heart rates. The means and standard deviations for each physiological parameter in the total group, the two subgroups, and in the separate group with multiple air bag collections are listed in Table 6.

For each group, maximal oxygen consumption was linearly regressed against maximal time using a least squares fit regression technique. The regression equations for the groups with standard error of estimates and correlation coefficients are shown in Table 7. The relationship of maximal treadmill time and maximal oxygen consumption with the (.95, .95) tolerance limits for the 1025 normal men are represented in Figure 5. The tolerance limits are constructed such that one can be 95% confident that at least 95% of future observations from the same population would fall within the limits.
Table 6. Mean with standard deviation for each of the physiological parameters of the four study groups.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Age (Yrs)</th>
<th>VO₂ (ccO₂/kg/min)</th>
<th>Maximal Treadmill Time (minutes)</th>
<th>Maximal Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total group of 1025 men</td>
<td>34.2 (7.2)</td>
<td>36.15 (6.13)</td>
<td>16.5 (2.9)</td>
<td>186.1 (10.8)</td>
</tr>
<tr>
<td>Subgroup with heart rate of 180 or less</td>
<td>37.2 (7.5)</td>
<td>34.11 (5.77)</td>
<td>15.3 (2.8)</td>
<td>173.6 (7.1)</td>
</tr>
<tr>
<td>(N=317)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subgroup with heart rate greater than 180</td>
<td>32.8 (6.6)</td>
<td>37.07 (6.07)</td>
<td>17.1 (2.8)</td>
<td>191.7 (6.8)</td>
</tr>
<tr>
<td>(N=708)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group with multiple air bag collections</td>
<td>38.0 (9.0)</td>
<td>36.74 (5.58)</td>
<td>15.2 (2.9)</td>
<td>183.3 (10.7)</td>
</tr>
<tr>
<td>(N=127)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Equations for the regression lines of maximal oxygen consumption plotted against maximal treadmill time in the four study groups. (r = correlation coefficient; S.E.E. = standard error of estimate)

1. TOTAL GROUP OF 1025 MEN
   Maximal oxygen consumption = 11.12 + 1.51 (maximal treadmill time)
   (S.E.E. = 4.26; r =+.72)

2. SUBGROUP OF 317 MEN WITH HEART RATE OF 180 OR LESS
   Maximal oxygen consumption = 11.29 + 1.49 (maximal treadmill time)
   (S.E.E. = 3.92; r =+.74)

3. SUBGROUP OF 708 MEN WITH HEART RATE GREATER THAN 180
   Maximal oxygen consumption = 11.25 + 1.51 (maximal treadmill time)
   (S.E.E. = 4.41; r =+.69)

4. GROUP OF 127 MEN WITH MULTIPLE EXPIRED AIR BAGS COLLECTED
   Maximal oxygen consumption = 11.19 + 1.70 (maximal treadmill time)
   (S.E.E. = 2.84; r =+.87)

Figure 5. Regression line with (.95, .95) tolerance limits based on 1025 normal men exercised using the Balke protocol.

(With the permission of the C. V. Mosby Company and the American Heart Journal.)
The data from the groups of individuals whose maximal treadmill time was 10, 15, and 20 minutes are compared in Table 8. The mean maximal oxygen consumption can be compared to the values estimated by the computed regression lines. Also, the (.95, .95) tolerance limits computed from the regression analyses can be compared.

Table 8. Comparison of the derived regression analyses in the groups

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Maximal treadmill time (minutes)</th>
<th>Number of subjects</th>
<th>Mean VO$_2$ (ccO$_2$/kg/min) with standard deviation</th>
<th>Estimated VO$_2$ from regression line</th>
<th>(.95, .95) tolerance limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total group of 1025 normal men</td>
<td>10</td>
<td>12</td>
<td>27.61 (4.31)</td>
<td>26.26</td>
<td>16.64-35.88</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>111</td>
<td>34.01 (4.23)</td>
<td>33.83</td>
<td>24.69-42.97</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>87</td>
<td>41.57 (5.13)</td>
<td>41.40</td>
<td>32.11-50.70</td>
</tr>
<tr>
<td>Subgroup of 708 men with maximal heart rates greater than 180</td>
<td>10</td>
<td>4</td>
<td>29.60 (3.39)</td>
<td>26.35</td>
<td>15.99-36.72</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>79</td>
<td>34.35 (4.40)</td>
<td>33.90</td>
<td>24.21-43.59</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>68</td>
<td>41.32 (5.23)</td>
<td>41.45</td>
<td>31.67-51.22</td>
</tr>
<tr>
<td>Subgroup of 317 men with maximal heart rates of 180 or less</td>
<td>10</td>
<td>8</td>
<td>26.61 (4.56)</td>
<td>26.24</td>
<td>16.64-35.83</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>32</td>
<td>33.18 (3.70)</td>
<td>33.71</td>
<td>24.78-42.64</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>19</td>
<td>42.44 (4.78)</td>
<td>41.18</td>
<td>31.68-50.68</td>
</tr>
<tr>
<td>Group with multiple air bag collections (N=127)</td>
<td>10</td>
<td>3</td>
<td>30.03 (1.38)</td>
<td>28.21</td>
<td>20.41-36.01</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>19</td>
<td>36.08 (2.15)</td>
<td>36.72</td>
<td>29.67-43.78</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>4</td>
<td>45.57 (4.26)</td>
<td>45.23</td>
<td>37.51-52.95</td>
</tr>
</tbody>
</table>

The mean heart rate and oxygen consumption during the last minute and the minute before maximal time for the 127 subjects who had multiple air bags collected are shown in Table 9. The mean difference between these two times was determined and there was a significant difference (p < .001) for both heart rate and oxygen consumption at these two times. Only 22% of these subjects showed an absolute plateau of oxygen consumption, 13% showed a plateau in heart rate and 3.8% showed a plateau of both parameters. No spurious measurements approached maximal time and the final minute was valid for determining maximal oxygen consumption.

Table 9. Data from the 127 subjects with multiple expired air bags collected.

<table>
<thead>
<tr>
<th></th>
<th>Minute prior to Maximal Time</th>
<th>Last Minute of Treadmill Exercise</th>
<th>Mean Difference</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate</td>
<td>179</td>
<td>183</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>Oxygen Consumption</td>
<td>34.8</td>
<td>36.7</td>
<td>2.0</td>
<td>0.2</td>
</tr>
</tbody>
</table>

(With the permission of the C. V. Mosby Company and the American Heart Journal. 61)
Fifty-five men (5.1%) of the total group walked for longer than 22 minutes. Despite walking from 23 to 44 minutes, their mean “peak” oxygen consumption was approximately 45 ml O₂/kg/min. This was the approximate mean aerobic cost of performing the 22d minute of the Balke protocol and was consistent with the 22% grade limit of the treadmill.

The simultaneous determinations of maximal oxygen consumption using the Beckman instruments and the Micro-Scholander technique showed a correlation coefficient (r) of 0.97.

DISCUSSION

This study demonstrates that the maximal oxygen consumption can differ widely among individuals for any maximal treadmill time. There is too much overlap of the range of maximal oxygen consumption for maximal treadmill times to accurately separate those with different aerobic capacities except in a very gross fashion. Apparently, other factors than maximal oxygen consumption are operating in determining the treadmill performance of an individual.

Balke based his nomogram for predicting maximal oxygen consumption on his test performed with a heart rate limit of 180, since he felt that maximal oxygen consumption was achieved by this heart rate limit. However, early in this study, it was noted that this was not true and heart rate limitations were removed. The regression equations for the two heart rate subgroups did not differ significantly (Table 7).

The group with multiple air bag collections confirmed the accuracy of the expired air collection techniques. No inconsistent measurements approached maximal time and the final minute was valid for determining maximal oxygen consumption. Plateauing of oxygen consumption at maximal effort was found in only one-fifth of the subjects. This has been a consistent finding using any continuous protocol in our laboratory. The maximal and "maximal minus one minute" values were significantly different (p < .001).

In the comparison of treadmill protocols presented in the preceding section, the data showed that treadmill experience could increase treadmill performance time without an increase in maximal oxygen consumption. This effect was avoided in this study by considering subjects with no previous treadmill experience. Submaximal oxygen consumptions measured at 10 and 15 minutes in the Balke protocol during the previous study (Table 10) can be compared to maximal oxygen consumption for individuals whose maximal treadmill times were 10 and 15 minutes. This comparison suggests that those exercising maximally at these times are less efficient than those exercising submaximally.

Table 10. Submaximal oxygen consumption of fifteen subjects whose maximal treadmill time exceeded fifteen minutes during their first treadmill walk

<table>
<thead>
<tr>
<th>Treadmill Time (minutes)</th>
<th>Submaximal Mean oxygen consumption with standard deviation (ccO₂/kg/min)</th>
<th>Maximal Mean oxygen consumption with standard deviation (ccO₂/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>24.30 (2.0)</td>
<td>27.61 (4.31)</td>
</tr>
<tr>
<td>15</td>
<td>32.6 (2.5)</td>
<td>34.01 (4.23)</td>
</tr>
</tbody>
</table>

It appears that the maximal performance time in a continuous progressive treadmill protocol can only grossly predict maximal oxygen consumption. Thus, the accurate determination of an individual's functional aerobic capacity or the indirect estimate of maximal cardiac output, requires the collection and analysis of expired air.

Section II

D

THE EFFECTS OF AGE AND EARLY CARDIOVASCULAR DISEASE UPON MAXIMAL EXERCISE PERFORMANCE IN THE USAF AIRCREW POPULATION

Increasing age has been shown to be associated with a decline in the heart rate response to maximal exercise, a decrease in cardiac output, and a decline in maximal oxygen consumption. The delineation of the effect of age on these parameters is particularly important in order to allow differentiation between the effects produced by early cardiovascular disease, physical fitness, and those produced by age. Whether a correlation exists between maximal
oxygen consumption, blood pressure response to maximal exercise and maximal heart rate response to exercise and the risk for future development of cardiovascular disease has not been determined. Prior to investigating such correlations, the values that can be expected for these age-related parameters in our population must be defined. This section deals with the USAFSAM experience with treadmill exercise testing of asymptomatic aircrewmen referred to the Aeromedical Consultation Service for evaluation.

METHODS

Subjects seen in the period from 1965 to 1969 were selected for this study because the currently used methods of evaluation were adopted for all referral subjects in 1965. Men with valvular heart disease, pericardial disorders, congenital heart disease, cardiomyopathies, bundle branch block, pre-excitation syndromes, left ventricular hypertrophy with "strain," significant resting repolarization abnormalities, anemia, electrolyte abnormalities, and those requiring medications or with on-going symptoms of ischemic heart disease were excluded from consideration. There were 1640 men remaining who were placed into one of six groups according to the following order of precedence: (1) ischemic heart disease group (IHD) - those with a history of symptoms consistent with IHD and/or who developed significant Q waves on serial ECGs but were asymptomatic at the time of evaluation; (2) nonspecific ST segment change group (NSSTC) - those with a serial change from a normal resting ECG to one showing ST segment depression but with a change that was minimal (less than 0.5 mm.), not persistent and rarely present at the time of USAFSAM evaluation; (3) nonspecific T wave change group (NSTWC) - those with a serial change from a normal resting ECG to a fasting ECG showing repolarization abnormalities consisting of low amplitude T waves and rarely flat or inverted T waves; (4) high blood pressure group (HBP) - those with untreated labile or essential hypertension; (5) normal group (NORMAL) - those referred for evaluation of any minor medical, psychiatric, ophthalmologic, otolaryngologic, or flying problems who on routine examination, including history, physical, chest x-ray and resting ECG, were considered to be free of any cardiovascular abnormality; and (6) astronaut, test pilot group (ASTRO) - those referred for medical evaluation prior to entry into special projects and who on routine examination were considered to be free of any cardiovascular abnormality. As an example of the precedence of subject grouping, if a subject referred for a medical evaluation prior to entry into a special project was found to have an abnormality by history, physical examination or on his resting ECG, he was placed into the appropriate higher precedence group. Following is an outline of the methods of evaluation adopted at the USAFSAM in 1965 and currently utilized.

The periodic ECGs given all USAF flying personnel are reviewed at the USAFSAM. Approximately 4000 ECGs are reviewed each month. Repolarization abnormalities (nonspecific T wave or ST segment changes) representing a change from a previously normal ECG are found in approximately 1% of all the periodic ECGs. Individuals whose ECGs show these changes are required to have a repeat fasting ECG and a double Master's test at their Air Force base. If the changes are persistent or if the double Master's test shows any abnormality, the individual is referred to the USAFSAM. Other referrals are made to consider individuals with a question of medical, psychiatric, ophthalmologic, otolaryngologic or flying problems for continuation on flying status.

At the USAFSAM, a thorough history and physical examination, chest x-ray, blood chemistry profile, percent body fat by the tritium dilution technique, resting ECG, vectorcardiogram, Holter monitoring, double Master's test and maximal treadmill test were performed on all referrals. Maximal treadmill testing was performed using a constant treadmill speed of 3.3 mph (90 meters/min) and an increasing incline of 1% each minute. During the final minutes of exercise, the subject's expired air was collected in neoprene balloons and gas measurements were made using Tissot and Beckman gas analyzers (LB-1 for CO2 and E-2 for O2). The gas analyzers were calibrated routinely with gases analyzed by the Micro-Scholander technique. Indirect cuff blood pressures were obtained each minute throughout the entire procedure. Subjects were encouraged to continue exercise to exhaustion without handrail support. The test was stopped if a systolic blood pressure greater than 260 mmHg or a diastolic blood pressure greater than 140 mmHg were reached, if the subject developed significant symptoms, or if the physician felt that the subject's well-being was endangered. The test was not necessarily stopped if arrhythmias or ST depression occurred.

RESULTS

Of the 1640 men in this study, 1317 men were considered to have achieved a maximal response to exercise and had a normal electrocardiographic response to exercise. The regression equations for total treadmill time in minutes, maximal heart rate response and maximal oxygen consumption regressed against age in these 1317 men are presented in Table 11. The mean, standard deviation and percentile values for treadmill performance and the risk factor data for the normal subject group are presented in Table 12.

Body composition studies using tritium dilution illustrate the increase in body fat with increasing age. Since body weight and weight to height ratio change little between the age groups, the increase in body fat suggests a decrease in lean body mass with increasing age. The ratio of increase in body fat from the young age group to the oldest age group is identical to the ratio of decrease in maximal oxygen consumption. The mean values of serum cholesterol rose significantly (p < 0.05) from the younger to the older age groups. Although the serum triglycerides also showed an upward trend with increased age, the differences were not statistically significant.
Table 11. Treadmill performance parameters regressed on age for the men in the 1640 study group who had a normal test and gave a maximal effort

<table>
<thead>
<tr>
<th>All Groups  (N = 1317)</th>
<th>MTMT = 23.2 - 0.19 (age)</th>
<th>S.E.</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3.23</td>
<td>r = -0.41</td>
</tr>
<tr>
<td></td>
<td>MHR = 207 - 0.54 (age)</td>
<td>10.20</td>
<td>r = -0.43</td>
</tr>
<tr>
<td></td>
<td>VO2 = 47.6 - 0.33 (age)</td>
<td>5.88</td>
<td>r = -0.39</td>
</tr>
<tr>
<td></td>
<td>VO2 = 14.1 + 1.32 (MTMT)</td>
<td>4.38</td>
<td>r = +0.73</td>
</tr>
<tr>
<td>Astros (N = 306)</td>
<td>MTMT = 22.2 - 0.083 (age)</td>
<td>3.21</td>
<td>r = -0.08</td>
</tr>
<tr>
<td></td>
<td>MHR = 206 - 0.47 (age)</td>
<td>9.15</td>
<td>r = -0.16</td>
</tr>
<tr>
<td></td>
<td>VO2 = 48.1 - 0.24 (age)</td>
<td>5.77</td>
<td>r = -0.13</td>
</tr>
<tr>
<td>Normals (N = 710)</td>
<td>MTMT = 19.8 - 0.11 (age)</td>
<td>2.70</td>
<td>r = -0.32</td>
</tr>
<tr>
<td></td>
<td>MHR = 199 - 0.43 (age)</td>
<td>10.06</td>
<td>r = -0.33</td>
</tr>
<tr>
<td></td>
<td>VO2 = 43.2 - 0.23 (age)</td>
<td>5.45</td>
<td>r = -0.32</td>
</tr>
<tr>
<td>HBP (N = 111)</td>
<td>MTMT = 23.5 - 0.22 (age)</td>
<td>3.38</td>
<td>r = -0.43</td>
</tr>
<tr>
<td></td>
<td>MHR = 212 - 0.82 (age)</td>
<td>9.71</td>
<td>r = -0.52</td>
</tr>
<tr>
<td></td>
<td>VO2 = 49.1 - 0.41 (age)</td>
<td>5.85</td>
<td>r = -0.46</td>
</tr>
<tr>
<td>NSTWC (N = 124)</td>
<td>MTMT = 20.9 - 0.15 (age)</td>
<td>2.85</td>
<td>r = -0.35</td>
</tr>
<tr>
<td></td>
<td>MHR = 211 - 0.75 (age)</td>
<td>10.15</td>
<td>r = -0.47</td>
</tr>
<tr>
<td></td>
<td>VO2 = 39.1 - 0.15 (age)</td>
<td>5.28</td>
<td>r = -0.20</td>
</tr>
<tr>
<td>NSSTC (N = 33)</td>
<td>MTMT = 17.6 - 0.07 (age)</td>
<td>2.90</td>
<td>r = -0.16</td>
</tr>
<tr>
<td></td>
<td>MHR = 209 - 0.68 (age)</td>
<td>9.68</td>
<td>r = -0.44</td>
</tr>
<tr>
<td></td>
<td>VO2 = 39.2 - 0.15 (age)</td>
<td>6.30</td>
<td>r = -0.17</td>
</tr>
<tr>
<td>IHD (N = 23)</td>
<td>MTMT = 17.7 - 0.09 (age)</td>
<td>2.53</td>
<td>r = -0.16</td>
</tr>
<tr>
<td></td>
<td>MHR = 211 - 0.83 (age)</td>
<td>13.43</td>
<td>r = -0.27</td>
</tr>
<tr>
<td></td>
<td>VO2 = 25.5 - 0.10 (age)</td>
<td>3.64</td>
<td>r = -0.12</td>
</tr>
</tbody>
</table>

Legend: MTMT = Maximal Treadmill Time in minutes  
VO2 = Maximal Oxygen Consumption  
Age = Years of Age  
MHR = Maximal heart rate

Table 12. Means, (standard deviations), and .05 - .95 percentiles of the measured parameters of those in the normal subject group who performed a maximal effort and had a normal treadmill test

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Weight (lbs)</th>
<th>Wt/Ht **</th>
<th>% Body Fat</th>
<th>Cholesterol (mg%)</th>
<th>Triglycerides (mg%)</th>
<th>Maximal O2 Consumption (cc/kg-min)</th>
<th>Maximal Treadmill Time (mins)</th>
<th>Maximal Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29 (N= 219-206)*</td>
<td>170 (22)</td>
<td>2.41 (.28)</td>
<td>19.7 (6.1)</td>
<td>189 (37)</td>
<td>27.6 (6.1)</td>
<td>17.1 (3.0)</td>
<td>189 (10)</td>
<td>170-204</td>
</tr>
<tr>
<td>30-39 (N= 315-283)</td>
<td>173 (20)</td>
<td>2.46 (.26)</td>
<td>22.0 (5.8)</td>
<td>207 (40)</td>
<td>34.6 (5.3)</td>
<td>15.5 (2.7)</td>
<td>183 (10)</td>
<td>166-200</td>
</tr>
<tr>
<td>40-53 (N= 274-202)</td>
<td>174 (20)</td>
<td>2.48 (.26)</td>
<td>23.0 (5.8)</td>
<td>222 (42)</td>
<td>33.2 (5.1)</td>
<td>14.9 (2.5)</td>
<td>180 (11)</td>
<td>160-198</td>
</tr>
</tbody>
</table>

* (N = number; the first number is all the subjects in the age group, the second number is the least number of subjects in any parameter block due to missing data)

** (Mean height was 70.2 inches for the three age groups with a S.D. of 2.5 inches)
The blood pressure data are of special interest as shown in Figures 6 and 7 taken from previously published data. There was no age related difference in mean baseline systolic pressure as illustrated in Figure 6. This finding may well be related to selection out of the population of those individuals with problems that would result in increased systolic pressures. The baseline diastolic pressure did show higher mean values in the older age groups. During exercise, the systolic pressure increased normally while there was essentially no change in diastolic pressures. The difference between baseline and maximal systolic and diastolic pressures was not different among the age groups; however, the actual levels of both systolic and diastolic pressure at maximal exercise were significantly higher in the older age groups. In Figure 7 is shown a comparison of blood pressure response in patients in the age range 40-49 years, who were categorized as normal, early mild hypertension, nonspecific repolarization changes on electrocardiogram (NSTWC) or coronary heart disease (CHD). The blood pressure response of hypertensive patients was not qualitatively different from the response of the NSTWC and CHD group, although the actual pressures were higher at rest and at maximal exercise. The normal group diastolic pressure showed a significantly lower rate of rise (p < 0.05) with exercise than the other groups. The hypertensive group started with an elevated resting blood pressure level which stayed proportionately higher throughout exercise than the other groups. Considerable variation existed in the response pattern of blood pressure to exercise in individuals. Although an elevation of diastolic blood pressure to 120 mmHg or greater occurred five times as frequently in the hypertensive group as in the normal group, this level was sufficiently frequent in normal individuals to make it of dubious value for differentiation in the individual case. Figure 8 shows results derived from a subgroup of normal men with their activity status classified. Activity status had no effect on the blood pressure response. The long-term risk significance of the blood pressure response to treadmill exercise remains to be determined.

The analysis of maximal heart rate regressed on age showed a decline with age as has been found by many investigators. Lester and colleagues have reviewed the studies of maximal heart rate and presented their results in a group of 190 male volunteers ranging in age from 15 to 75. The standard error of estimate was quite comparable between their study and our study. They found a regression slope of -0.411 beats/minute/year for both active and sedentary subjects. The regression slopes obtained in our population varied greatly between subgroups, probably because of the poor correlation between HR max and age. The determination of values for maximal heart rate has clinical importance since some investigators recommend heart rate targeted submaximal exercise tests. The end point of these tests is usually 75 to 90% of the mean maximal heart rate for the subject's age.

The analysis of maximal oxygen consumption regressed on age showed a decline with age as has been found by many investigators. Dehn and Bruce have reviewed both the cross-sectional and longitudinal studies of maximal oxygen consumption and presented their results in a group of 86 healthy men with various activity levels. Analysis of their cross-sectional data yielded the following regression equation for maximal oxygen consumption: $VO_2 = 49.93 - 0.278 \times (age)$. This is comparable to the regression equation obtained for all groups in Table 1. The X intercept of 49.93 found by Dehn and Bruce compared to 47.6 in our regression analysis of the total group can possibly be explained by the different treadmill protocols used. Approximately a 49 greater maximal oxygen consumption is obtained using the Bruce protocol than with the Balke protocol. The poor correlation coefficient and wide tolerance limits for maximal oxygen consumption for age are likely due to the fact that multiple factors besides age are involved. For instance, maximal oxygen consumption is dependent upon an individual's genetic endowments and previous training as well as his current activity habits, cardiovascular status and age.
The regression equations agree with the findings of many other investigators that treadmill performance and aerobic capacity decline with age. It was disappointing that the correlation coefficients of the equations were low and the tolerance limits for age were wide. The wide bands of normal limits for these parameters resulted in much overlap between the groups. Epidemiological follow-up will be necessary to determine if these measurements have any risk factor value.

At the USAFAM, maximal oxygen consumption is measured on all referred aircrewmen. Results are correlated with the individual's exercise habits and clinical cardiovascular status. In aircrewmen with waiverable cardiovascular abnormalities, serial measurements of maximal oxygen consumption can help detect changes in cardiac function. Sedentary individuals without evidence of cardiovascular disease, but with a maximal oxygen consumption less than the mean for their age, are encouraged to begin an exercise program in an effort to improve their overall cardiovascular fitness. An exercise program can facilitate the modification of known CHD risk factors, and hopefully decrease the risk for the future development of cardiovascular disease.

Section III

ELECTROCARDIOGRAPHIC ASPECTS OF EXERCISE TESTING

A. Background

Master was one of the earliest investigators who attempted to evaluate the electrocardiographic response of individuals to a standardized workload. (6, 66) Using the initial criteria for an abnormal response, (67) Master showed excellent accuracy with this test when he used it in patients with known coronary heart disease, (68) but when applied to apparently healthy groups, up to 25% of the subjects had what was considered an abnormal response. (69-71) With additional experience and re-evaluation of the original criteria, emphasis was placed on the importance of ST segment depression as the primary sign of myocardial ischemia.

Table 13 summarizes the studies screening asymptomatic men using the double Master's test or a test with a comparable workload. These studies included follow-up data and it is apparent that postexercise ST segment depression identified a high risk group of men. The epidemiological terms used to describe the performance of screening tests are defined in table 14. (77)

<table>
<thead>
<tr>
<th>Main Investigator</th>
<th>Population Size</th>
<th>Years Observed</th>
<th>Exercise ECG Response</th>
<th>Number and % of total Population</th>
<th>Number Developing CHD (% of ECG Response Group)</th>
<th>Risk Ratio</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mattingly</td>
<td>300</td>
<td>15</td>
<td>Abnormal</td>
<td>7 (2.3%)</td>
<td>3 (43%)</td>
<td>5</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>293 (97.7%)</td>
<td>25 (9%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brody</td>
<td>756</td>
<td>4</td>
<td>Abnormal</td>
<td>23 (3%)</td>
<td>16 (70%)</td>
<td>14</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>733 (97%)</td>
<td>36 (5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bellet</td>
<td>795</td>
<td>3</td>
<td>Abnormal</td>
<td>95 (12%)</td>
<td>13 (14%)</td>
<td>10</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>700 (88%)</td>
<td>10 (1.4%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doyle</td>
<td>2003</td>
<td>5</td>
<td>Abnormal</td>
<td>75 (4%)</td>
<td>64 (95%)</td>
<td>13</td>
<td>34%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>1928 (96%)</td>
<td>125 (6.5%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rumball</td>
<td>660</td>
<td>6</td>
<td>Abnormal</td>
<td>65 (10%)</td>
<td>15 (23%)</td>
<td>15</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>595 (90%)</td>
<td>9 (1.5%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(With permission from Academic Press and Preventive Medicine. 73)
Table 14. Definitions of Epidemiological Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Formula</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>( \frac{TP}{\text{all subjects who developed CHD}} \times 100 )</td>
<td>Probability of developing CHD given an abnormal test</td>
</tr>
<tr>
<td>Predictive value</td>
<td>( \frac{TP}{TP + FP} \times 100 )</td>
<td>Probability of developing CHD given an abnormal test</td>
</tr>
<tr>
<td>Predictive error</td>
<td>( \frac{FN}{FN + TN} \times 100 )</td>
<td>Probability of developing CHD given a normal test</td>
</tr>
<tr>
<td>Specificity</td>
<td>( \frac{TN}{FP + TN} \times 100 )</td>
<td>Probability of developing CHD given a normal test</td>
</tr>
<tr>
<td>Risk ratio</td>
<td>( \frac{\text{predictive value}}{\text{predictive error}} )</td>
<td>Ratio of developing CHD given an abnormal test to developing CHD given a normal test</td>
</tr>
</tbody>
</table>

Legend:
- FN (false negatives) = those with normal tests who developed CHD
- TN (true negatives) = those with normal tests who did not develop CHD
- FP (false positives) = those with abnormal tests who did not develop CHD
- TP (true positives) = those with abnormal tests who developed CHD

The primary problem with the double Master's test is that it lacks sufficient sensitivity, particularly when applied to a relatively young, active population like USAF aircrewmen. The experience at the USAPGAM is in concert with the studies of Sheffield, et al.\(^{78}\) that demonstrated a highly variable heart rate response to the double Master's two-step test. It is obvious that an exercise test that fails to significantly elevate the heart rate is unlikely to precipitate electrocardiographic changes in that individual unless there exists an advanced state of coronary insufficiency. The relatively poor sensitivity of the double Master's test was documented by Sheffield, et al.\(^{78}\) Also, in a study using a similar workload, Doyle and Kinch\(^{75}\) found only 30% of the 263 men who developed angina, myocardial infarctions or who died suddenly over a 13 year follow-up had an abnormal response to exercise as the first sign of CHD.

It seemed logical to many clinicians that increasing the exercise load over the modest exercise of the double Master's test would increase the diagnostic yield and perhaps permit diagnosis at an earlier stage of the disease process. As discussed earlier in Section IIA, the early efforts in cardiovascular evaluation were oriented to the measurement of performance parameters, but in more recent years, the electrocardiographic response to exercise stress testing has become an important aspect of an evaluation for coronary artery disease.\(^{79}\) Table 15 summarizes the studies screening asymptomatic populations using maximal or near maximal exercise testing. These studies have not included a follow-up of the populations screened. Table 16 presents the findings in three epidemiological studies with follow-up data using both the double Master's test and maximal treadmill testing.

Tables 13, 15, and 16 summarized the results of the studies screening asymptomatic men with exercise tests. These studies were reviewed in detail in a previous publication.\(^{79}\) The percentage of abnormal responders in the populations screened using the double Master's test or a test with a similar workload varied from 2.3% to 12% and the percentage of abnormal responders in the population studies using near maximal or maximal treadmill testing varied from 1% to 20%. In the studies with follow-up analysis of the population screened, the sensitivity of exercise testing for detecting latent coronary heart disease varied from 10% to 62%. In follow-up studies using both the double Master's and the maximal treadmill test, maximal treadmill testing was 1.5 to 3 times more sensitive than the double Master's test in predicting the future occurrence of coronary heart disease. Risk ratios from 5 to 18 were reported. However, the probability of developing coronary heart disease over the follow-up period given an abnormal response (predictive value) varied from 13.6% to 85%. As far as can be discerned, these studies did not include individuals with the known cause of false positive responses, such as valvular heart disease, congenital heart disease, cardiomyopathies, pericardial disorders, vasoregulatory asthenia, resting or hyperventilation induced repolarization abnormalities, electrolyte abnormalities, or those on medication. Part of the explanation for the different results obtained in these studies was that different populations were screened. However, these divergent results can also be explained by the different techniques utilized for exercise testing by the different investigators. Nonetheless, they demonstrate the value of exercise testing in screening asymptomatic men for latent CHD.
Table 15. Studies screening asymptomatic populations using maximal or near maximal exercise testing without follow-up results reported.

<table>
<thead>
<tr>
<th>Main Investigator</th>
<th>Exercise Protocol</th>
<th>Age Range</th>
<th>Percentage with Abnormal Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lester [80]</td>
<td>Bruce Test (submaximal at 85% of age adjusted maximal heart rate or &quot;GXT&quot; and maximal)</td>
<td>40-75</td>
<td>GXT: 1% Maximal: 4.5%</td>
</tr>
<tr>
<td>Riley [81]</td>
<td>&quot;GXT&quot;</td>
<td>50-69</td>
<td>17.6%</td>
</tr>
<tr>
<td>Goldbarg [82]</td>
<td>Bruce Test (Maximal)</td>
<td>30-60 (Mean 44)</td>
<td>14%</td>
</tr>
<tr>
<td>Berkson [83]</td>
<td>Balke-Ware Treadmill test (near maximal)</td>
<td>40-59</td>
<td>20%</td>
</tr>
<tr>
<td>Cumming [84]</td>
<td>Maximal or near maximal bicycle ergometer exercise</td>
<td>40-45</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46-50</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51-60</td>
<td>17.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61-65</td>
<td>37%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40-65</td>
<td>Total: 12%</td>
</tr>
<tr>
<td>Cali [85]</td>
<td>Near maximal treadmill exercise (heart rate limit 160)</td>
<td>30-65</td>
<td>Anterior lead: 7.3% Inferior lead: 4.5% Total: 11.8%</td>
</tr>
<tr>
<td>Spangler [86]</td>
<td>Near maximal treadmill exercise</td>
<td>28-66 (Mean 44)</td>
<td>1.4%</td>
</tr>
<tr>
<td>Kemp [87]</td>
<td>Maximal treadmill exercise</td>
<td>31-70</td>
<td>11%</td>
</tr>
<tr>
<td>Kattus [88]</td>
<td>Near maximal treadmill exercise</td>
<td>23-39</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40-49</td>
<td>5.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-59</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60-69</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70-79</td>
<td>33.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23-79</td>
<td>Total: 9.6%</td>
</tr>
</tbody>
</table>

Table 16. Comparative follow-up studies of the double Master's test and maximal treadmill testing

<table>
<thead>
<tr>
<th>Main Investigator</th>
<th>Years Observed</th>
<th>Exercise Test Used</th>
<th>Exercise ECG Response</th>
<th>Number and % of total population</th>
<th>Number developing CHD (% of ECG Response Group)</th>
<th>Risk Ratio</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruce [89]</td>
<td>5</td>
<td>Double Master's (≥ 0.5 mm ST depression)</td>
<td>Abnormal</td>
<td>8 (3.6%)</td>
<td>2 (25%)</td>
<td>18</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>213 (96.4%)</td>
<td>3 (1.4%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bruce Test (lead CB5)</td>
<td>Abnormal</td>
<td>22 (10%)</td>
<td>3 (13.6%)</td>
<td>13.6</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>199 (90%)</td>
<td>2 (1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aronow [90]</td>
<td>2.5</td>
<td>Double Master's (≥ 1.0 mm ST depression)</td>
<td>Abnormal</td>
<td>4 (4%)</td>
<td>1 (25%)</td>
<td>7</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>96 (96%)</td>
<td>3 (3.1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bruce Test (lead torso V5)</td>
<td>Abnormal</td>
<td>13 (13%)</td>
<td>3 (23%)</td>
<td>20</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>87 (87%)</td>
<td>1 (1.1%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Froelicher [91]</td>
<td>6.3</td>
<td>Double Master's (≥ 0.5 mm ST depression)</td>
<td>Abnormal</td>
<td>52 (3.7%)</td>
<td>14 (27%)</td>
<td>11.3</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>1338 (96.3%)</td>
<td>32 (2.4%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balke Test (lead CC5)</td>
<td>Abnormal</td>
<td>140 (10%)</td>
<td>28 (20%)</td>
<td>14.3</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Normal</td>
<td>1250 (90%)</td>
<td>18 (1.4%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Correlations of the maximal exercise test response with coronary angiographic findings have been largely confined to symptomatic patients. Mason and his associates\(^9\) reported 84% of 67 patients with typical angina pectoris had 1.0 mm or more of ST segment depression with straightening or downsloping during or after near-maximal exercise on an ergometer, while only 56% of 41 of the same angina patients had a positive double Master's two-step test. These investigators also found excellent correlation between coronary cinearteriographic demonstration of severe coronary lesions in 84 patients and the presence of 1.0 mm or more ST segment depression with straightening or downsloping. Only 4 patients with arteriographically normal vessels had positive exercise tests and 11 subjects with significant coronary lesions had negative exercise tests. Aiscoop, et al\(^9\) in a series of 96 patients with chest pain and a normal ECG at rest, compared the results of history, serum lipids, a graded exercise test (GXT), and in 91 patients a modified two-step test to the findings at coronary arteriography. They used the index of merit in a range of 0 to 1 for each factor compared to the coronary arteriogram and reported indices of 0.59 for history, 0.53 for the GXT, 0.37 for serum β-lipoprotein, 0.28 for serum cholesterol and 0.26 for the two-step test. In 30 subjects where history, GXT and serum β-lipoprotein were concordant, the agreement with coronary arteriograms was 0.93. In 64 patients the concordant history and GXT yielded an index of 0.82. In the overall group the best result was obtained using two or three factors for an index of merit of 0.67. Martin, et al\(^9\) studied 100 patients with maximal treadmill exercise and coronary arteriography. Sixteen of their patients had resting ECG evidence of antecedent myocardial infarction, 65 patients had chest pain and 35 patients underwent coronary arteriography as a part of consideration for coronary bypass surgery. The maximal treadmill test had a true negative rate of 89% and a true positive rate of 62% using 1.0 mm or greater ST segment depression as the criterion for abnormal response. Less strict criteria of ≥ 0.75 and ≥ 0.5 mm S-T depression increased the true positive rates to 68 and 84% respectively but reduced the true negative rate to 78 and 57% respectively.

Only a small number of asymptomatic men have been studied with coronary angiography. One study conducted at the USAF School of Aerospace Medicine\(^9\) evaluated 76 asymptomatic aircrewmen with coronary angiography, all of whom had abnormal responses to maximal treadmill exercise with a normal resting electrocardiogram but most had a history of resting repolarization changes. Approximately one-half of these individuals had normal coronary arteries by arteriography and the others had some degree of angiographic coronary disease. In contrast to the studies in symptomatic populations, our findings demonstrated a lower predictive value of the maximal treadmill test. The true predictive value cannot as yet be defined, but it will doubtless be dependent upon the characteristics of the group being studied.

**SECTION III**

**B**

**SCREENING ASYMPTOMATIC USAF AIRCREWMEN FOR LATENT CORONARY ARTERY DISEASE: THE RESULTS OF LABORATORY, DOUBLE MASTER'S TEST AND MAXIMAL TREADMILL TEST SCREENING**

The importance of specific experience with any finding or test result in a special population of interest such as the aircrewmen cannot be overemphasized. As discussed in the earlier portions of this monograph, the variation in the study populations reported in the literature has made it very difficult to compare results and to draw specific cross inference. This report reviews a portion of the USAFSAM experience with asymptomatic aircrewmen who were referred for aeromedical evaluation. It attempts to define the frequency and types of responses, the correlation between tests, and the influence of disease and age upon the results of exercise stress testing.

**METHODS**

The population of this study was the same 1640 aircrewmen who were described earlier in the methods of Section II D. The electrocardiogram recorded with the treadmill exercise stress test utilized fluid column anodized silver-silver chloride electrodes with meticulous care given to skin preparation to keep impedance levels to 5,000 ohms or less as checked by an AC impedance meter. A bipolar lead between the right and left fifth intercostal spaces at the anterior axillary line (lead X or CC5) was used and interpreted consistently while several other bipolar leads have been recorded but used primarily for arrhythmia diagnosis. The bipolar ECG data was recorded during the baseline period with the subject supine and standing and then continuously recorded during and after exercise on a conventional multichannel ECG machine and on analog tape and monitored on an oscilloscope. In addition, standard leads I, II, aVF, V2 and V5 were recorded on a conventional multichannel ECG machine prior to exercise and at immediate recovery, two-minute recovery, five-minute recovery and eight-minute recovery. Thirty seconds of hyperventilation prior to exercise was added to the protocol in 1967. All of the ECG recordings associated with the exercise test were microfilmed. A physician was in attendance at all times to monitor both the subject's condition and his ECG. Recovery ECG tracings were recorded with the subject supine for at least eight minutes.

The microfilmed copies of the resting, exercise and postexercise ECG records of the entire study group were reinterpreted for this study. All borderline and abnormal records were coded by one investigator, carefully noting the pattern and degree of ST segment change and the leads involved. One-tenth millivolt or more of horizontal or downward sloping ST segmental depression in
relation to the PR segment in bipolar lead X during or after treadmill exercise or in the standard leads after treadmill exercise was interpreted as an "abnormal" response. Less than one-tenth millivolt of ST segmental depression or J-junctional depression with an inadequate ST segment slope (less than 1 mv/sec) was coded as a “borderline” response. One-twentieth millivolt (0.05) or more horizontal or downward sloping ST segmental depression in the standard leads after the double Master's test was interpreted as an "abnormal" response.

RESULTS

The number of men in each group, their mean age, and the percent with an abnormal response to treadmill testing are shown in Table 17. The prevalence of abnormal responses to treadmill testing in each group by age decades is shown in Table 18. The prevalence of abnormal responses to the double Master's test by age decades and by groups is shown in Table 19. The relative yields of the double Master's test and the treadmill test are compared in Table 20.

TABLE 17 ASYMPTOMATIC MEN STUDIED AT USAFSAM 1965-1968

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>NUMBER (%)</th>
<th>MEAN AGE (SD)</th>
<th>% WITH ABNORMAL ECG RESPONSE TO TREADMILL TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>340 (20.7)</td>
<td>31 (3)</td>
<td>2.1</td>
</tr>
<tr>
<td>NORMAL</td>
<td>808 (49.3)</td>
<td>36 (8)</td>
<td>2.4</td>
</tr>
<tr>
<td>HBP</td>
<td>130 (7.9)</td>
<td>39 (7)</td>
<td>3.9</td>
</tr>
<tr>
<td>NSTWC</td>
<td>196 (12.0)</td>
<td>41 (7)</td>
<td>17.3</td>
</tr>
<tr>
<td>NSSTC</td>
<td>101 (6.2)</td>
<td>42 (8)</td>
<td>47.5</td>
</tr>
<tr>
<td>IND</td>
<td>65 (4.0)</td>
<td>46 (4)</td>
<td>47.7</td>
</tr>
<tr>
<td>ALL</td>
<td>1640 (100)</td>
<td>37 (7)</td>
<td>8.8</td>
</tr>
</tbody>
</table>

TABLE 18 INCIDENCE OF ABNORMAL ECG RESPONSE TO TREADMILL BY AGE

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>20-29 YEARS</th>
<th>30-39 YEARS</th>
<th>40-53 YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>1.8% (2/109)</td>
<td>2.2% (5/224)</td>
<td>0% (0/77)</td>
</tr>
<tr>
<td>NORMAL</td>
<td>0.9% (2/219)</td>
<td>2.5% (8/315)</td>
<td>3.3% (9/274)</td>
</tr>
<tr>
<td>HBP</td>
<td>0% (0/14)</td>
<td>2.1% (1/47)</td>
<td>5.8% (4/69)</td>
</tr>
<tr>
<td>NSTWC</td>
<td>0% (0/11)</td>
<td>12.7% (8/63)</td>
<td>21.3% (26/122)</td>
</tr>
<tr>
<td>NSSTC</td>
<td>55.6% (5/9)</td>
<td>30.8% (8/26)</td>
<td>53.0% (35/66)</td>
</tr>
<tr>
<td>IND</td>
<td>(0/0)</td>
<td>66.7% (4/6)</td>
<td>45.8% (22/59)</td>
</tr>
<tr>
<td>ALL</td>
<td>2.5% (9/362)</td>
<td>5.0% (34/681)</td>
<td>16.9% (101/597)</td>
</tr>
</tbody>
</table>

(ABNORMAL = 1 mm OR MORE ST SEGMENT DEPRESSION)

TABLE 19 INCIDENCE OF ABNORMAL ECG RESPONSE TO DOUBLE MASTER'S TEST BY AGE

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>20-29 YEARS</th>
<th>30-39 YEARS</th>
<th>40-53 YEARS</th>
<th>ALL AGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>0% (0/328)</td>
<td>0.6% (3/539)</td>
<td>0.4% (1/281)</td>
<td>0.35% (4/1148)</td>
</tr>
<tr>
<td>NORMAL</td>
<td>0% (0/14)</td>
<td>0% (0/47)</td>
<td>0% (0/69)</td>
<td>0% (0/130)</td>
</tr>
<tr>
<td>HBP</td>
<td>0% (0/11)</td>
<td>4.8% (3/63)</td>
<td>5.7% (7/122)</td>
<td>5.1% (10/196)</td>
</tr>
<tr>
<td>NSTWC</td>
<td>0% (0/9)</td>
<td>15.4% (4/26)</td>
<td>30.3% (20/66)</td>
<td>23.8% (24/101)</td>
</tr>
<tr>
<td>NSSTC</td>
<td>0% (0/0)</td>
<td>33.3% (2/6)</td>
<td>22.0% (3/59)</td>
<td>23.1% (15/65)</td>
</tr>
<tr>
<td>IND</td>
<td>0% (0/4)</td>
<td>1.8% (12/681)</td>
<td>6.9% (41/597)</td>
<td>3.2% (53/1640)</td>
</tr>
<tr>
<td>ALL</td>
<td>0% (0/362)</td>
<td>1.8% (12/681)</td>
<td>6.9% (41/597)</td>
<td>3.2% (53/1640)</td>
</tr>
</tbody>
</table>

(ABNORMAL = 0.5 mm OR MORE ST SEGMENT DEPRESSION)

TABLE 20 COMPARISON OF INCIDENCE OF ABNORMAL ECG RESPONSE TO TREADMILL TEST AND DOUBLE MASTER'S TEST

<table>
<thead>
<tr>
<th>GROUPS</th>
<th>TM</th>
<th>DM</th>
<th>RELATIVE YIELD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>2.30%</td>
<td>0.35%</td>
<td>6.6 X</td>
</tr>
<tr>
<td>NORMAL</td>
<td>3.90%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>HBP</td>
<td>17.30%</td>
<td>5.10%</td>
<td>3.4 X</td>
</tr>
<tr>
<td>NSTWC</td>
<td>47.50%</td>
<td>23.80%</td>
<td>2.0 X</td>
</tr>
<tr>
<td>NSSTC</td>
<td>47.70%</td>
<td>23.10%</td>
<td>2.1 X</td>
</tr>
<tr>
<td>ALL</td>
<td>8.80%</td>
<td>3.20%</td>
<td>2.7 X</td>
</tr>
</tbody>
</table>
HYPERTENSIVE SUBJECTS WITH AND WITHOUT RESTING REPOLARIZATION ABNORMALITIES

<table>
<thead>
<tr>
<th></th>
<th>MEAN HIGHEST BP (SD)</th>
<th>MEAN 3 DAY AVERAGE (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LABILE HYPERTENSIVE</td>
<td>153 (± 17)</td>
<td>135 (± 10)</td>
</tr>
<tr>
<td>ESSENTIAL HYPERTENSIVES</td>
<td>167 (± 17)</td>
<td>154 (± 14)</td>
</tr>
</tbody>
</table>

The data regarding labile and essential hypertensives in this population and their percentage of abnormal treadmill responses are presented in Tables 21 and 22. The blood pressures recorded were those obtained during office examination.

DISCUSSION

Our results are in agreement with other reported series, with maximal treadmill exercise stress testing producing 2.7 times as many abnormal responses as did the double Master's test. In the ischemic heart disease (IHD) group, the prevalence of abnormal responses to maximal treadmill exercise was 47.7% which is somewhat less than the 62% true positive rate reported by Martin and associates using coronary angiography as an end point. This probably is a reflection of the particular population of patients seen at USAFSAM. Since all patients were prescreened and obviously ill patients were not referred for consultation and all patients were asymptomatic, our population of patients with a diagnosis of IHD were biased towards having mild disease. The frequency of patients who have had a silent myocardial infarction was much higher than the experience in hospital populations as was the frequency of patients who had a clinical myocardial infarction and were subsequently asymptomatic even when stressed with vigorous exertion. Our population was also younger than most hospital populations with CHD.

The prevalence of abnormal tests in the other groups is particularly interesting. Those patients who had documented serial S-T segment changes in the resting ECG had a prevalence of 47.5% abnormal responses to maximal treadmill exercise, essentially the same as the IHD group. This is particularly important in view of the fact that these S-T segment changes were not persistent and were rarely present at the time of the treadmill test. The difference between the prevalence of abnormal treadmill responses in patients who had a history of serial S-T segment changes on the resting ECG and those with T-wave changes points out the importance of specific classification of the repolarization status when the significance of the response to exercise is being studied.

Although long-term follow-up or coronary arteriography would be required to ascertain the relative sensitivity and specificity of the treadmill test response in these two groups, the increased prevalence of abnormal responses in the group with S-T segment changes is in keeping with the clinical impression that this ECG finding is more ominous than T-wave changes. We have been unable to correlate specific patterns of repolarization response to exercise in these patients with a history of repolarization changes on serial resting ECGs with angiographically demonstrated coronary disease.

It is also of interest that whether repolarization changes were present at the time of the treadmill test or had only been present in the past seemed to have no differential effect on the treadmill response. The differential in abnormal ECG responses to exercise between the S-T segment changes group and the T-wave changes group was also evident in the results of the double Master's test.

The hypertensive group had no abnormal responses to the double Master's test but did have an increased prevalence of abnormal responses to maximal treadmill exercise as compared to normals. Since patients were classified in only one diagnostic group, patients with blood pressure abnormalities were placed in the NSTWC group and the NSSTC group as shown in Table 22. There was a distinctly higher prevalence of abnormal responses in the essential hypertensive group in each diagnostic category. Whether this increased prevalence is specifically related to the higher blood pressure level, or is due to CHD cannot be answered from these data, but should be addressed in future studies.
The prevalence of abnormal tests increased in proportion to age. The age analysis of the groups suggested that the difference in abnormal tests between groups was at least partially related to age.

In our experience, maximal treadmill exercise has been a safe procedure. We have experienced no deaths in our series and no significant morbidity. At present, an abnormal ECG response to maximal treadmill exercise should be viewed in the context of the whole patient. There are many causes for an abnormal response in addition to ischemia or coronary disease and these must be considered in a given patient. As previously described, these causes have been screened for in our studies and subjects with these conditions eliminated from consideration or considered separately.

SECTION III

C

ABNORMALITIES OF CARDIAC RHYTHM WITH TREADMILL EXERCISE

It is well known that exercise can induce transient disturbances in cardiac rhythm and that exercise-induced rhythm disturbances are more common in patients with coronary heart disease. However, the significance of a cardiac rhythm disturbance occurring during exercise is not clear and reports on this subject are conflicting. The occurrence of a cardiac rhythm disturbance in a flyer has significance beyond the specific aspect of its relationship to underlying disease diagnosis; that is, does the occurrence increase the risk of future recurrence of the same or more significant rhythm disturbances that could cause incapacitation? As with the diagnosis of disease, flying safety becomes the central issue and demands a decision regarding prognosis and disposition for flying duties.

This study reports the experience of the USAFSAM with cardiac rhythm disturbances associated with maximal treadmill exercise in aircrew members referred for aeromedical evaluation.

METHODS

The population of this study was the same 1640 aircrewmen who were described earlier in the methods of Section II D and Section III B. The subjects were grouped in the same manner as described in Section II D. Premature ventricular contractions (PVCs) were considered to be frequent if in any series of 50 beats, 20% or more were PVCs. PVCs were considered to be "ominous" when they increased to frequent rather than decreased with exercise, when two consecutive PVCs occurred with other PVCs that increased with exercise, and when three or more PVCs occurred consecutively.

RESULTS

Atrial arrhythmias were encountered in 4.6% of the study group and the occurrence was not associated with specific disease classification, age group, or treadmill electrocardiographic response. One subject developed atrial fibrillation during recovery from exercise.

<table>
<thead>
<tr>
<th>FREQUENCY OF OCCURRENCE</th>
<th>NUMBER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINGLE PVC</td>
<td>178</td>
<td>10.9</td>
</tr>
<tr>
<td>OCCASIONAL PVC</td>
<td>222</td>
<td>13.5</td>
</tr>
<tr>
<td>FREQUENT PVCs</td>
<td>89</td>
<td>5.4</td>
</tr>
<tr>
<td>2 CONSECUTIVE PVCs</td>
<td>31</td>
<td>1.9</td>
</tr>
<tr>
<td>2 CONSECUTIVE PVCs PLUS OTHERS</td>
<td>17</td>
<td>1.0</td>
</tr>
<tr>
<td>3 CONSECUTIVE PLUS OTHERS</td>
<td>10</td>
<td>0.6</td>
</tr>
<tr>
<td>3 CONSECUTIVE PVCs ONLY</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>4 OR MORE CONSECUTIVE PVCs</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>554</td>
<td>33.8</td>
</tr>
</tbody>
</table>

The prevalence and patterns of occurrence of PVCs are presented in Table 23. Twenty-four percent of the men had single or occasional PVCs. The NSSTC group and the 40-53 year age group with single or occasional PVC occurrence rates of 33.7% and 29.8% respectively, were statistically different from the normal group (p < .05). Sixty-five percent of the single or occasional PVCs occurred in late exercise; 25% occurred at some other time during exercise, and 10% occurred only during recovery. The occurrence rates of PVCs other than single or occasional are shown by group in Table 24 and by age decade in Table 25. The IHD group and the 40-53 year age group had a greater occurrence of PVCs (other than single or occasional) and this was statistically different from the normal group (p < .05). The initial time of occurrence of these types of PVCs is shown in Table 26. The "ominous" PVC patterns and their frequency of occurrence are listed in Table 27. Thirteen men had exercise tests stopped at submaximal levels because of arrhythmias. The prevalence of "ominous"
**TABLE 24**

NUMBER AND PERCENTAGE OF SUBJECTS IN THE STUDY GROUP WITH PVCs OTHER THAN SINGLE OR OCCASIONAL BY GROUP CLASSIFICATION

<table>
<thead>
<tr>
<th>GROUP</th>
<th>NUMBER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>13</td>
<td>3.8</td>
</tr>
<tr>
<td>NORMAL</td>
<td>81</td>
<td>10.0</td>
</tr>
<tr>
<td>HBP</td>
<td>14</td>
<td>10.8</td>
</tr>
<tr>
<td>NSTWC</td>
<td>21</td>
<td>10.7</td>
</tr>
<tr>
<td>NSSTC</td>
<td>13</td>
<td>12.9</td>
</tr>
<tr>
<td>IHD</td>
<td>12</td>
<td>18.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>154</td>
<td>9.4</td>
</tr>
</tbody>
</table>

**TABLE 25**

NUMBER AND PERCENTAGE OF SUBJECTS WITH PVCs OTHER THAN SINGLE OR OCCASIONAL BY AGE

<table>
<thead>
<tr>
<th>AGE</th>
<th>NUMBER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>24</td>
<td>6.6</td>
</tr>
<tr>
<td>30-39</td>
<td>52</td>
<td>7.6</td>
</tr>
<tr>
<td>40-53</td>
<td>78</td>
<td>13.1</td>
</tr>
</tbody>
</table>

**TABLE 26**

INITIAL TIME OF APPEARANCE OF PVCs OTHER THAN SINGLE OR OCCASIONAL

<table>
<thead>
<tr>
<th>TIME OF APPEARANCE</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>LATE EXERCISE</td>
<td>40%</td>
</tr>
<tr>
<td>THROUGHOUT EXERCISE</td>
<td>30%</td>
</tr>
<tr>
<td>EARLY IN EXERCISE</td>
<td>15%</td>
</tr>
<tr>
<td>MID EXERCISE</td>
<td>11%</td>
</tr>
<tr>
<td>RECOVERY ONLY</td>
<td>4%</td>
</tr>
</tbody>
</table>

**TABLE 27**

'OMINOUS' PATTERNS OF PVC OCCURRENCE

<table>
<thead>
<tr>
<th>PVCs THAT INCREASE TO FREQUENT WITH EXERCISE</th>
<th>[N=5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>THREE CONSECUTIVE PVCs</td>
<td>[N=5]</td>
</tr>
<tr>
<td>TWO CONSECUTIVE PVCs PLUS OTHERS</td>
<td>[N=9]</td>
</tr>
<tr>
<td>THREE CONSECUTIVE PVCs PLUS OTHERS</td>
<td>[N=10]</td>
</tr>
<tr>
<td>FOUR OR MORE CONSECUTIVE PVCs PLUS OTHERS</td>
<td>[N=2]</td>
</tr>
<tr>
<td></td>
<td>[N=31]</td>
</tr>
</tbody>
</table>

**TABLE 28**

NUMBER AND PERCENTAGE OF SUBJECTS WITH 'OMINOUS' PATTERNS OF PVC OCCURRENCE BY GROUP CLASSIFICATION

<table>
<thead>
<tr>
<th>GROUP</th>
<th>NUMBER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>3</td>
<td>0.9</td>
</tr>
<tr>
<td>NORMAL</td>
<td>14</td>
<td>1.7</td>
</tr>
<tr>
<td>HBP</td>
<td>3</td>
<td>2.3</td>
</tr>
<tr>
<td>NSTWC</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>NSSTC</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>IHD</td>
<td>6</td>
<td>9.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>31</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**TABLE 29**

NUMBER AND PERCENTAGE OF SUBJECTS WITH 'OMINOUS' PATTERNS OF PVC OCCURRENCE BY AGE

<table>
<thead>
<tr>
<th>AGE</th>
<th>NUMBER</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29</td>
<td>3</td>
<td>0.8</td>
</tr>
<tr>
<td>30-39</td>
<td>7</td>
<td>1.0</td>
</tr>
<tr>
<td>40-53</td>
<td>21</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Arrhythmias by group is shown in Table 28 and by age decades is shown in Table 29. The frequency of occurrence was statistically greater in the IHD group and the older age groups (p < .001).
DISCUSSION

The overall incidence of some form of cardiac rhythm disturbance recorded during the treadmill test period of 40.4% demonstrates that arrhythmias occurring during strenuous exercise testing or in the recovery period are very common. The figure in this study is in concert with the 36.6% overall incidence previously reported from this laboratory by Brambell, et al. (100) and with the incidence reported by McHenry, et al. (102).

The occurrence rates of PVCs were age-related and greater in the IHD group, but the normal group and younger age group had a surprisingly high prevalence of PVCs. The PVCs were more frequently initiated in the later stages of exercise and thus occurred at higher heart rates. Although it is difficult to classify beats of ectopic foci accurately with respect to origin, particularly at high heart rates, the higher occurrence rates with increasing exercise in all groups makes it doubtful that exercise induction of PVCs can be viewed as evidence for heart disease in a given individual.

The relatively low incidence of supraventricular arrhythmias and the lack of correlation with age, disease, category, treadmill response and exercise stage suggests that supraventricular arrhythmias may have less chance of being prognostically significant than ventricular events and may be unrelated to the mechanisms responsible for ventricular arrhythmias. Our arbitrary classification of "ominous" rhythm disturbances was based primarily upon previous clinical experiences in hospital populations and the associations of these types of rhythm disturbances with serious heart disease. Therefore, this classification may prove to be unwarranted as follow-up data is acquired. There was an increased incidence of these "ominous" patterns in the older age groups in those with an abnormal ECG response, and in the IHD group.

These data establish the expected incidence and behavior of cardiac rhythm disturbances associated with treadmill exercise in a flying population. We do not believe that the occurrence of exercise-induced rhythm disturbances alone can be equated with organic heart disease. However, the significance of these rhythm disturbances has not been established and we currently view ominous ectopic tachyarrhythmias as contraindicating continuation in flying duties. We also feel that the frequency of the rhythm disturbances observed during exercise demands careful ECG monitoring during exercise stress testing.

SECTION III

D

AN EPIDEMIOLOGIC STUDY OF ASYMPTOMATIC MEN SCREENED WITH MAXIMAL TREADMILL TESTING

The need for diagnostic techniques reliably capable of identifying individuals with latent CAD (coronary artery disease) is nowhere better illustrated than in the flying population because of the need to maintain public safety and the need to direct efforts at prevention of morbidity and mortality. (1,2,103) The deficiencies of the data assessing the specific significance of exercise stress tests have been discussed earlier in this section. The purpose of this prospective epidemiological study was to demonstrate the sensitivity, specificity and predictive value of exercise testing in screening an asymptomatic population for latent CHD. This study has been presented in less detail previously. (101)

METHODS

The study group consisted of the same 1640 aircrewmen described earlier in the methods of Section II D.

The follow-up consisted of validation of the status of each subject during the year 1973 by the use of current USAF active duty rosters, retirement rosters, Veterans Administration records, death rosters, medical records and/or direct health questionnaires. In all, 1390 men were able to be traced. Those that could not be traced were those who left the Air Force without medical retirement and before 20 years service, civilians and a smaller number of subjects who were members of the military services of foreign nations who were evaluated at USAFSAM. Special emphasis was placed upon questionnaire follow-up in the disease groups, in individuals with an abnormal response to treadmill testing and in those with an arrhythmia during treadmill testing. End points for CHD were angina, acute myocardial infarction and sudden death. Abnormal coronary angiographic finding in asymptomatic men or autopsy findings of coronary artery disease in non-cardiac deaths were not used as end points. Medical records subsequent to the USAFSAM evaluation and autopsy reports were obtained whenever possible.

RESULTS

The population groups and numbers successfully followed are presented in Table 30 along with the mean age and age range of the group followed. The lowest follow-up success (62.9%) was in the special candidate group (astro). These individuals and those in the normal group were younger and
the attrition rate from the Air Force prior to retirement was higher. The foreign military aircrew-men were concentrated almost exclusively in the normal group and no follow-up was possible in these individuals. The follow-up period ranged from 4.1 to 8.4 years with a mean of 6.3 years.

Table 30. Number of subjects in each group and the age statistics.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Original Number</th>
<th>Number with Follow-up</th>
<th>% Follow-up</th>
<th>Mean Age</th>
<th>(S.D.)</th>
<th>Age Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>340</td>
<td>214</td>
<td>62.9</td>
<td>31.1</td>
<td>(2.4)</td>
<td>25-42</td>
</tr>
<tr>
<td>NORMAL</td>
<td>808</td>
<td>710</td>
<td>87.9</td>
<td>36.7</td>
<td>(8.1)</td>
<td>20-53</td>
</tr>
<tr>
<td>HBP</td>
<td>130</td>
<td>123</td>
<td>94.6</td>
<td>39.9</td>
<td>(7.2)</td>
<td>22-54</td>
</tr>
<tr>
<td>NSTWC</td>
<td>196</td>
<td>186</td>
<td>94.8</td>
<td>41.4</td>
<td>(6.6)</td>
<td>23-52</td>
</tr>
<tr>
<td>NSSTC</td>
<td>101</td>
<td>94</td>
<td>93.1</td>
<td>42.7</td>
<td>(7.0)</td>
<td>25-52</td>
</tr>
<tr>
<td>IHD</td>
<td>65</td>
<td>63</td>
<td>96.9</td>
<td>45.7</td>
<td>(4.4)</td>
<td>34-52</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1640</td>
<td>1390</td>
<td>84.8</td>
<td>37.6</td>
<td>(8.0)</td>
<td>20-54</td>
</tr>
</tbody>
</table>

LEGEND: Astro - special project subjects; Normals - men referred for evaluation of minor health problems; HBP - men with labile or essential hypertension; NSSTC - men who developed transient serial ST segment changes on their routine ECGs; NSTWC - men who developed serial TW changes on their routine ECGs; and IHD - asymptomatic men who developed Q waves on their routine ECGs and/or had a history of chest pain.

(With the permission of the American Journal of Cardiology.)

Of the 142 individuals in all groups who had an abnormal response to treadmill testing, 115 (81%) were followed by medical questionnaire and/or medical records, 12 (8.4%) were identified as having died from any cause, 13 (9.2%) were known alive by listing on an active USAF roster, and 2 (1.4%) could not be traced. Two individuals of this group had normal coronaries at autopsy and four had cardiac catheterizations with normal coronary arteriograms.

Of the 98 individuals with a borderline abnormal response to treadmill testing, 40 (40.8%) were followed by medical questionnaire and/or medical records, 3 (3.1%) were identified as having died from any cause, 50 (51%) were known alive by listing on an active USAF roster and 5 (5.1%) could not be traced. None of the 3 deaths were related to CHD.

Of the 30 individuals who had an "ominous" arrhythmia associated with treadmill testing, 20 (66.7%) were followed by medical questionnaire and/or medical records, 2 (6.7%) were identified as having died from coronary heart disease, 7 (23.3%) were known alive by listing on an active USAF roster and 1 (3.3%) could not be traced.

The incidence of morbidity and mortality due to CHD observed over the follow-up period is given in Table 31. The epidemiological terms used in the tables and discussion were defined in Table 14.

Table 31. Clinical presentation of 46 men who developed morbidity and mortality secondary to CHD over the follow-up period.

| 23 men with classical angina (7 with known abnormal coronary angiograms, 4 treated with coronary by-pass surgery) |
| 7 men with symptomatic myocardial infarctions (1 who died in the hospital) |
| 16 men who died suddenly (10 with documented autopsies all showing severe coronary artery disease) |
The results using maximal treadmill testing and the double Master's test as screening techniques within the subject groups are presented in Tables 32 and 33. The same data for maximal treadmill testing but by age groups are presented in Table 34. The 40 to 54 year age group was also analyzed by excluding the men in the IHD and NSSTC groups. This age group contained 78% of the latter two groups and their influence was evident.

### Table 32. Results using maximal treadmill (TM) testing to screen for latent coronary artery disease within the subject groups.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>NO. (%) WHO DEVELOPED CHD</th>
<th>NO. (%) WITH ABNORMAL TM</th>
<th>SENSITIVITY</th>
<th>PREDICTIVE VALUE</th>
<th>SPECIFICITY</th>
<th>RISK RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astro</td>
<td>0</td>
<td>4 (1.9%)</td>
<td>--</td>
<td>(0/4)</td>
<td>98%</td>
<td>(0/0)</td>
</tr>
<tr>
<td>Normal</td>
<td>7 (1.0%)</td>
<td>19 (2.7%)</td>
<td>(2/7) 28.6%</td>
<td>(2/19) 10.5%</td>
<td>98%</td>
<td>(10.5/0.7) 14.5 X</td>
</tr>
<tr>
<td>HBP</td>
<td>6 (4.9%)</td>
<td>5 (4.1%)</td>
<td>(3/6) 50.0%</td>
<td>(3/5) 60.0%</td>
<td>98%</td>
<td>(60/2.5)   24.0 X</td>
</tr>
<tr>
<td>NSTWC</td>
<td>8 (4.3%)</td>
<td>34 (18.3%)</td>
<td>(8/6) 75.0%</td>
<td>(8/34) 21.7%</td>
<td>84%</td>
<td>(17.6/1.3) 13.5 X</td>
</tr>
<tr>
<td>NSSTC</td>
<td>8 (8.5%)</td>
<td>47 (50.0%)</td>
<td>(4/8) 50.0%</td>
<td>(4/47) 8.5%</td>
<td>50%</td>
<td>(8.5/8.5) 1.0 X</td>
</tr>
<tr>
<td>IHD</td>
<td>17 (27.0%)</td>
<td>31 (49.2%)</td>
<td>(13/17) 76.5%</td>
<td>(13/31) 41.9%</td>
<td>61%</td>
<td>(42/12.5) 3.4 X</td>
</tr>
<tr>
<td>TOTAL</td>
<td>46 (3.3%)</td>
<td>140 (10.1%)</td>
<td>(28/46) 60.9%</td>
<td>(28/140) 20.0%</td>
<td>92%</td>
<td>(20/1.4) 14.3 X</td>
</tr>
</tbody>
</table>

### Table 33. Results using the double Master's (DM) test to screen for latent coronary artery disease within the subject groups.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>NO. (%) WHO DEVELOPED CHD</th>
<th>NO. (%) WITH ABNORMAL DM</th>
<th>SENSITIVITY</th>
<th>PREDICTIVE VALUE</th>
<th>RISK RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>NORMAL</td>
<td>7 (1.0%)</td>
<td>4 (0.6%)</td>
<td>(0/7)</td>
<td>(0/4)</td>
<td>(0/1) 0 X</td>
</tr>
<tr>
<td>HBP</td>
<td>6 (4.9%)</td>
<td>0</td>
<td>(0/6)</td>
<td>--</td>
<td>(0/4.5) 0 X</td>
</tr>
<tr>
<td>NSTWC</td>
<td>8 (4.3%)</td>
<td>10 (5.4%)</td>
<td>(0/8)</td>
<td>(0/10)</td>
<td>(0/4.5) 0 X</td>
</tr>
<tr>
<td>NSSTC</td>
<td>8 (8.5%)</td>
<td>24 (25.5%)</td>
<td>(6/8) 75.0%</td>
<td>(6/24) 25.0%</td>
<td>(25/2.9) 8.6 X</td>
</tr>
<tr>
<td>IHD</td>
<td>17 (27.0%)</td>
<td>14 (22.2%)</td>
<td>(8/17) 47.1%</td>
<td>(8/14) 57.1%</td>
<td>(57.1/18.4) 3.1 X</td>
</tr>
<tr>
<td>TOTAL</td>
<td>46 (3.3%)</td>
<td>52 (3.7%)</td>
<td>(14/46) 30.4%</td>
<td>(14/52) 26.9%</td>
<td>(26.9/2.4) 11.2 X</td>
</tr>
</tbody>
</table>
Table 34. Results using maximal treadmill testing to screen for latent coronary artery disease within age groups.

<table>
<thead>
<tr>
<th>AGE GROUP</th>
<th>NO. (%) WHO DEVELOPED CHD</th>
<th>NO. (%) WITH ABNORMAL TM</th>
<th>SENSITIVITY</th>
<th>PREDICTIVE VALUE</th>
<th>SPECIFICITY</th>
<th>RISK RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-29 (N = 253)</td>
<td>0 (0%)</td>
<td>8 (3.2%)</td>
<td>--</td>
<td>(\frac{0}{6})</td>
<td>96.8%</td>
<td>--</td>
</tr>
<tr>
<td>30-39 (N = 563)</td>
<td>8 (1.4%)</td>
<td>31 (5.5%)</td>
<td>(\frac{4}{18})</td>
<td>50.0%</td>
<td>95.1%</td>
<td>17.2 X</td>
</tr>
<tr>
<td>40-54 (N = 574)</td>
<td>38 (6.6%)</td>
<td>101 (17.6%)</td>
<td>(\frac{24}{38})</td>
<td>63.2%</td>
<td>85.6%</td>
<td>8.0 X</td>
</tr>
<tr>
<td>40-54 without IHD and NSSTC groups (N = 451)</td>
<td>17 (3.8%)</td>
<td>39 (8.6%)</td>
<td>(\frac{10}{17})</td>
<td>58.8%</td>
<td>93.6%</td>
<td>15.1 X</td>
</tr>
</tbody>
</table>

A significant statistical difference (p < .01) was found in CHD morbidity and mortality between the combined Astro and Normal groups and the other groups. There was also a difference (p < .001) in the prevalence of abnormal responses to treadmill testing between the Astro and Normal groups and the NSTWC, NSSTC, and IHD groups. However, the mean ages of the subjects with these findings in the various groups are very similar (Table 35).

Table 35. Analysis of the ages of the men when seen at the USAFSAM from 1965 to 1969 who had abnormal TM tests and those who later developed end points for coronary heart disease.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>MEAN AGE OF THOSE WITH ABNORMAL TM (S.D.)</th>
<th>MEAN AGE OF THOSE WHO LATER DEVELOPED CHD (S.D.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astro</td>
<td>31.5 (4.2)</td>
<td>--</td>
</tr>
<tr>
<td>Normal</td>
<td>40.1 (9.0)</td>
<td>44.7 (6.1)</td>
</tr>
<tr>
<td>HBP</td>
<td>45.2 (6.2)</td>
<td>44.7 (6.6)</td>
</tr>
<tr>
<td>NSTWC</td>
<td>44.2 (5.4)</td>
<td>45.0 (3.7)</td>
</tr>
<tr>
<td>NSSTC</td>
<td>43.0 (7.6)</td>
<td>40.9 (4.4)</td>
</tr>
<tr>
<td>IHD</td>
<td>44.7 (4.6)</td>
<td>45.6 (3.8)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>43.1 (7.0)</td>
<td>44.0 (5.3)</td>
</tr>
</tbody>
</table>

The weight-height ratio, weight, serum cholesterol and the triglycerides of the men with abnormal treadmill responses and of the men who developed CHD end points were compared to a group of normal men of the same mean age. No statistically significant differences were found except for a slightly higher mean cholesterol in the men with CHD end points (p < .05). Maximal heart rate, maximal oxygen consumption and maximal treadmill time were similarly analyzed and no significant statistical differences were found.

(With the permission of the American Journal of Cardiology. 91)
Orthostatic ST segment depression was very rare in this population, but it did not rule out the development of CHD in men with abnormal treadmill tests. Pre-exercise hyperventilation caused ST segment depression in only two men who had abnormal treadmill tests, neither of whom developed CHD. The occurrence of 0.1 mv or more of horizontal ST segment depression during early or mid exercise that became up-going during later exercise did not rule out the development of CHD. Of those with abnormal treadmill tests who developed CHD, 14% had changes during exercise alone, 18% had changes only postexercise, and 68% had changes in both periods. Of those with abnormal treadmill tests, 11% had abnormal treadmill tests but did not develop CHD. A total of ST segment depression in the bipolar X lead only with less than 0.1 mv or no changes in other leads. The X lead was one of the abnormal leads in all men who had both abnormal treadmill tests and developed CHD with the exception of one individual detected by V5 alone.

The frequency and pattern of occurrence of arrhythmias in this subgroup were similar to the data presented for the entire group. The occurrence of PVCs was related to age and presence of CHD but was not a practical means of identifying a higher risk group except when associated with data presented for the entire group. The occurrence of PVCs was related to age and presence of subclinical cardiomyopathies or myocarditis. Further follow-up of false positive responders will be necessary to define their prognosis.

Comparison of Tables 32 and 33 shows that the double Master's test was relatively insensitive as a screening tool in this asymptomatic population. Though the total risk ratio and the probability of developing CHD given an abnormal test were comparable to treadmill testing, the inadequate sensitivity of the double Master's test was especially apparent in the first four groups. These findings emphasize the importance of replacing the double Master's test for screening asymptomatic men with a monitored heart rate targeted step test or bicycle test that can be used at facilities where a treadmill is not available.

The incidence of CHD morbidity and mortality and the frequency of abnormal treadmill responses appeared to be in proportion to the hypothetical risk for CHD of each group. However, analysis of the ages of the men in each group suggested that the differences were age related. The increased risk in CHD due to hypertension, history of symptoms suggestive of CHD, and ECG changes compatible with myocardial infarction have been demonstrated by other studies, but the development of repolarization changes in the serial ECGs of asymptomatic men requires further investigation in order to determine the significance of these findings.

Specificity varied between subject groups and Table 34 shows that specificity was inversely related to age. This was because both the incidence of CHD and the prevalence of abnormal responses to treadmill testing were directly related to age. An abnormal treadmill test was not related to an increased risk in the NSSTC group and was of lesser risk in the IHD group than in the other groups. As specified, the only way the NSSTC group could be recognized was by performing serial ECGs as is done on USAF aircrewmen after age 35 as part of the yearly examination requirements. The reason for the disappointing results of treadmill testing in the IHD and NSSTC groups is uncertain. However, both groups were at increased risk of CHD as compared to the other groups no matter what.
their treadmill response. The different values for the specificity and sensitivity of treadmill testing within subject and age groups were consistent with Bayes rule and demonstrate the naivete of asserting that treadmill testing has absolute values for these parameters. Bayes rule states that the diagnostic value of any test is dependent upon the incidence of the disease to be diagnosed within the population studied.\(^{(104)}\)

The sensitivity of treadmill testing for detecting latent CAD varied from 28.6% to 76.5% between subject groups and an overall sensitivity of 60.9% was demonstrated. Very little increase in yield was obtained by considering borderline responses or "ominous" arrhythmias.

Bruce and co-workers have demonstrated in their epidemiological study that the sensitivity of treadmill testing for the detection of latent CHD could be increased by performing treadmill tests every year on the population of their study.\(^{(105)}\) It is clearly possible in attempting to evaluate the sensitivity of a single test, that some individuals may have had a negative test at a point in time when no CHD or no hemodynamically significant lesion was present, and then subsequently developed a significant lesion. In the absence of a retest, this subsequent disease development would reduce the actual sensitivity and risk ratio of the treadmill test. It is not possible from our data to determine whether this has occurred and the method of calculating sensitivity and risk ratio does not allow for this situation. The rapid progression of coronary arterial lesions as demonstrated by Gensini and Kelly\(^{(106)}\) by arteriography suggests that this is a valid consideration.

The impressive risk ratio of 14.3 demonstrates that maximal treadmill testing is a valuable screening tool for latent CAD. Comparison to other risk factors in this population was limited because information regarding family history, cigarette habits, and activity status was not consistently available and lipid values were affected by seasonal and laboratory variations. However, the available data suggesting that an abnormal treadmill test functioned as an independent risk factor were in accord with the findings of Blackburn and co-workers.\(^{(107)}\) Maximal heart rate, maximal oxygen consumption, and maximal treadmill time were disappointing factors because of the wide tolerance limits found in normal men.\(^{(108)}\) The findings regarding treadmill exercise induced PVCs and their lack of specificity for morbidity and mortality of any kind in asymptomatic men were consistent with the data of McHenry and co-workers.\(^{(109)}\)

In conclusion, this study has demonstrated that the abnormal ECG response to exercise testing identifies a high risk group of men. However, the sensitivity and specificity limitations are apparent. An abnormal ECG response is not specific for the future ominous presentation of CHD and a normal response does not rule out this possibility. In appropriate instances where the minimal risk of coronary angiography is justified, this invasive procedure can determine the anatomic correlation of the functional ST segment response to exercise. To increase the sensitivity of screening techniques for detecting latent CAD, all risk factors of demonstrated value should be considered. Currently, at the USAFSAM, aircrews with an abnormal response to exercise testing are offered elective cardiac catheterization and returned to flying status if their coronary arteries show no angiographic lesions.

SECTION III
E

COMPUTER ANALYSIS OF EXERCISE ELECTROCARDIOGRAMS

INTRODUCTION:

The increasing application of computers to electrocardiographic analysis has focused emphasis on the necessity of optimum data acquisition. While the problems produced by less than optimal data acquisition systems are paramount when computer techniques are used, the problems are not limited to computer techniques. Berson and Pipberger\(^{(109)}\) demonstrated that an inadequate low frequency response in recording equipment could lead to serious distortions of repolarization. Normal ST segments may become depressed and downward sloping when the time constant is too short, as one example. Approximately 11% of records had significant ST errors in a group of sample tracings studied when a time constant of only 0.8 sec was used. In a later publication,\(^{(110)}\) these same authors pointed out that amplitude errors of 1 mm or more can be expected in approximately 20% of all records when the upper limit of frequency response of 50 Hz is used in the recording equipment. Figure 9 illustrates the effect of electrode and ECG machine impedance on the recorded signal. Figure 10 illustrates the complexity of the ECG signal gathering process. The need for good data acquisition is therefore pertinent to the subject of clinical electrocardiography. This section will present the USAFSAM experience with computer analysis of exercise electrocardiograms with emphasis on data collection techniques.
METHODS

Skin-Electrode interface:
The great majority of clinical ECGs are obtained using a metallic plate electrode and one of the commercially available electrolyte solutions for skin contact. Under these circumstances, skin-electrode impedance measurements of 50,000 to 100,000 ohms are common. This problem may be accentuated by marked impedance differentials between electrode pairs. An excellent reference work on electrodes is contained in Geddes textbook.111 The use of floating type electrodes combined with careful attention to skin preparation has enhanced our ability to obtain relatively noise and distortion free signals. The electrodes are anodized silver-silver chloride electrodes, 12 mm in diameter, encased in a lightweight plastic. A constant 2 mm distance between the skin and the contact surface of the electrode is maintained by embedding the electrode within the plastic holder. In this way electrical conduction is accomplished solely by the electrode paste. The electrodes are held in place by discs of tape with adhesive on both sides. This type of electrode design is especially effective in reducing baseline drift. We are currently evaluating a NASA floating electrode consisting of a silver-silver chloride crystalline pellet and an electrolyte solution that combines well with sweat.

Skin preparation for electrode placement is accomplished by careful cleansing of the skin with alcohol and acetone. Then the superficial horny layer of the epidermis in the area of electrode placement is removed by light sanding with fine sandpaper or by skin drilling. Care is taken to avoid abrading the skin to the point of bleeding. Muscle artifact, which is a frequent source of significant noise in exercise ECGs, may be largely obviated by placement of electrodes so that they do not overlie large muscle masses. Electrode impedance is checked between each pair of electrodes with a 10 Hz AC impedance meter and impedance levels of 5,000 ohms or less are required before electrode placement is considered adequate.

Lead Systems:
A wide variety of lead systems are in use for exercise testing today.112 This lack of standardization and the differences in various diagnostic features of the ECG between different leads make comparison of the reported studies of exercise testing difficult. Many investigators rely only on a bipolar lead, usually with the positive electrode at the left anterior axillary line in the fifth intercostal space, the same as precordial lead V5, but with various negative reference electrode placements rather than Wilson’s central terminal. Some of the reported reference electrode placements are illustrated in Figure 11. The bipolar leads are by convention prefixed by C and then by the negative electrode letter, e.g., CM6, CH5, CX5, CB6, CX5, CB5 and CC5. Other investigators have used modifications of the conventional ECG leads that would be suitable for exercise.92,114-116

The lead system used at USAFSAM is three-dimensional (illustrated in Figure 12). The X-lead is formed by electrodes placed in the right and left V5 position, the Y-lead by an electrode on the sternum at the level of the second intercostal space and an electrode in the left anterior axillary line at the sixth intercostal space, and the Z-lead by an electrode on the sternum at the level of the fourth intercostal space and an electrode directly posteriorly on the spine. The
Y-lead was derived after trials of various electrode placement (e.g., forehead-sacrum, forehead-left anterior iliac crest, manubrium-left lower abdomen) to achieve maximum reduction in muscle artifact. However, experience with the Y-lead has shown it to be more labile than other leads because it does not represent a superior-inferior orientation and it correlated poorly with angiographic coronary disease. We are currently evaluating a Y-lead made up of an electrode on the forehead and an electrode at the midclavicular line and the left lower rib cage margin. Preliminary results show less lability of the ST segment and an actual superior-inferior orientation.

Figure 11. Illustrations of exercise lead systems used by various investigators.

11 A - negative electrode placements used in various different bipolar leads;
11 B - Wilson's central terminal which is the negative reference in the standard precordial leads;
11 C - lead system with the limb electrodes placed on the torso for exercising;
11 D - ear ensiform precordial lead system which yields an ECG of uncertain value in screening for abnormal repolarization.
Figure 12 A

Figure 12 B

Figure 12. Exercise lead systems used at the USAFSAM.
12 A - previously used system;
12 B - currently used system.

**Data Preprocessing:**

The analog ECG signals are recorded in accordance with the instrument specification recommendations of the Committee on Electrocardiography, American Heart Association. A high input impedance ECG recorder with a frequency response from 0.15 to 100 Hz is used to record the 3 ECG leads on strip charts and the outputs from the pre-amplifiers are recorded on magnetic tape at 3-3/4 ips utilizing an Ampex FR-1800 frequency modulation (FM) analog data recorder for off-line analysis. At present, direct, real time analog to digital conversion of 3 channels of ECG data is accomplished using a Data General Nova 1230 minicomputer. However, all data reported in this monograph were processed off-line from FM tape.

The ECG signals recorded on magnetic tape were preprocessed by analog computer in order to prepare the data in an acceptable format for digital computer analysis. The ECG signals played at twice real time are low pass filtered (3 dB down at 100 Hz) using two dual channel active filters operating in the RC or constant delay mode to minimize 60 Hz interference. The signals are then applied to a scaling circuit programmed on an EAI TR-20 analog computer, which permits the adjustment of the signal amplitudes to bring them within the operating range of the microsadic A/D converter. An EAI MiniAC analog hybrid computer was programmed to generate a square wave signal, the leading edge of which coincided with a maximal rate of change of the QRS complex in the X lead. It also provides a beat by beat heart rate which is used in the selection of data for A/D conversion. An Astrodata time code translator is used to decode IRIG-B time code to locate the desired segment on the tape. Schematic diagrams of the circuitry are shown in Figure 13.

This analog trigger circuit operates on the principle that the rate of change of the R wave is unique when compared with other parts of the electrocardiographic signal. The circuit was designed to pass selectively those frequency components characteristic of the R wave and reject all others. The synchronization reference pulse was then generated when an empirically adjusted threshold value was exceeded by the point of maximum rate of change of the R wave. Our studies have shown this point to be stable, even in the presence of severe noise and respiratory modulation. The ECG signal is fed into the bandpass filter composed of amplifiers 22 and 25 and the associated capacitors. Switch SW16 permits the selection of either an upright or inverted complex, allowing the operator to choose the leading or trailing profile of the R wave as the signal from which the reference pulse will be generated. The majority of subjects in our studies have shown greater R-wave slope on the trailing edge in the X lead. The second band-pass filter consists of potentiometer 11, C3, C4, and amplifier 21. Potentiometer 11 serves as a gain control and potentiometer 21 is used as a threshold control which is adjusted so only the peak of the filtered R-wave at the output of amplifier 21 is positive. The filtered signal shown at the output of amplifier 21 is proportional to the rate of change of all negative sloping components of the input signal into amplifier 21, the positive components having been clipped off by diodes. The largest component displayed is a result of the high rate of change seen on the trailing edge of the R wave. The logic output of comparator 13 is high only when the output of amplifier 21 is positive, and is low otherwise. The flip-flop FF1 and gate 1 comprise a logic leading edge differentiator which produces a one microsecond pulse each time the output of comparator 13 goes high. Thus, the differentiator output at gate 1 consists of a series of one microsecond pulses, one for each R wave of the input ECG.
The output of the logic differentiator drives a monostable consisting of FF2, amplifiers 32 and 34, gate 2, R3, and C6. The output of this monostable is a one volt 20 millisecond pulse that is used as the ECG trigger signal.

A second output from the differentiator drives a counter/timer (CNTR). The CNTR turns on the A/D converter when pushbutton PB1 is activated and turns it off automatically after 65 beats have been digitized. PB2 can bypass this mechanism for continuous digitizing.

A third output from the differentiator drives a monostable which produces a 0.7 msec pulse for each R wave. This pulse is used to control the cardiotachometer which consists of a ramp generator (amplifier 12 and associated components), two track-store amplifiers (14 and 24), a divider (15) and a scaling amplifier (23). The ramp generator produces ramp voltage of constant slope which is reset to zero at each R wave. The track-store amplifiers capture and hold the final value of the ramp before it is reset and produce an output proportional to R-R interval. The divider converts this interval output to a frequency proportional output and the scaling amplifier provides a scale factor of 0.01 volts/beats per minute. Thus, the maximum heart rate of 240 produces a 2.4 volts reading on the miniAC voltmeter.

The insignificant delay in the analog circuit maintains the alignment of the derived reference pulses with the electrocardiographic complexes from which they were formed. The electrocardiographic data and associated synchronization pulses are then fed parallel into a CSC Micro-sadic A/D converter and digitized at a rate of 250 samples per second per channel and a series of one mv calibration pulses are also digitized. Quality control of the preprocessing procedure is accomplished by obtaining a hard copy recording of both the "raw" ECG data and the preprocessed data about to be digitized on an eight channel oscillograph. The digitized data are then stored on digital magnetic tape for subsequent digital computer analysis. The generation of a trigger pulse not only allows accurate determination of the fiducial point for the digital averaging process, but also allows for discrimination against most aberrant premature complexes due to differences in the maximal rate of change in the R wave and an adjustable refractory period that inhibits the generation of reference pulses by noise spikes and premature complexes occurring in the T-P interval.

**Digital Averaging:**

The initial step in processing the digital ECG data is the averaging procedure. All of the studies reported in this monograph were performed in a Philco 2000 digital computer. Data from the recumbent baseline, standing baseline, from the third minute of exercise, and from every fifth minute of exercise beyond this time up to and including the last minute of exercise and in the postexercise period the immediate 2, 5 and 6 minute period were averaged.
Initially, 100 consecutive QRS complexes were averaged for each time period, using four groups of 25 consecutive QRS complexes to determine the statistical variability of the data. The possibility that significant variation might occur in the ECG complexes over the time of 100 heart beats was investigated. In 10 normal subjects, 4 groups of 25 beats were averaged using sequential beats and compared to 4 groups of 25 beats formed by selecting every fourth beat. In each time period of the exercise test, comparisons were made in each of the measurements of interest, i.e., ST segment depression and ST segment slope. The consecutive beat averages had slightly higher variance than the alternate beat averages indicating there was some change over time, but the effect was not very pronounced.

A study was also carried out to determine the effect of reduction in the number of beats used to form the averaged beat, since computation time would be reduced if fewer beats than 100 were required. Ten normal individuals were used and average beats derived using 12, 24, 48 and 96 beats and analysis of variance performed. The results of this analysis demonstrated that the subject variability was large and as a result the variance with the larger sample was often greater than with lesser samples. We consequently revised our averaging program to process a maximum of 50 beats, but since it was desirable to average only data from similar heart rates, the instantaneous heart rate for each beat is determined before the beat is averaged. The averaging is terminated if this rate differs from the rate of the first beat of the average by more than plus or minus 5 beats per minute. If an average contained less than 10 beats, it was considered unacceptable and discarded.

Analysis of scalar parameters:

Our early analysis program utilized only the X-lead and measured ST segment depression and ST segment slope. Our current program determines 3 parameters of repolarization from the averaged scalar ECG data: ST depression, ST slope and ST area. The "area" is the algebraic area above and below the isoelectric baseline of an 80 msec segment beginning 60 msec after the R wave peak. Figure 14 illustrates these three scalar parameters computed from a normal individual's averaged lead X at a heart rate of 125 beats/min. The ST-depression is slightly depressed relative to the isoelectric PR segment and has an average value of (-)0.03 mv. The ST-slope is up-going and has a value of (+)2.5 mv/sec. The ST-area includes a negative area below the baseline and a small positive area above the baseline; the algebraic sum of these two areas is (-)4.0 mv sec. An example of an "abnormal" waveform from lead X at a heart rate of 125 beats/min is shown in Figure 15. The ST-depression is greater in magnitude than the preceding example and measures (-)0.18 mv. The ST-slope is opposite in direction from the "normal" waveform and has a value of (-)1.5 mv/sec. Similarly, the ST-area is entirely below the baseline with a value of (-)12.7 mv sec.

Figure 14. Illustrations of the scalar measurements made on the averaged complexes from each of the bipolar leads with normal values for lead X (CC5) at a heart rate of 125.

Figure 15. Illustration of the scalar measurements on the averaged complexes from lead X with an abnormal response.

(With the permission of Aerospace Medicine.)
Spatial ST-vector analysis:

In Figure 16 the derivation of the spatial ST segment is shown. Using averaged X, Y and Z data, spatial vectors are computed every 4 msec during an 80 msec period of repolarization beginning 60 msec after the peak of the R wave. When the tips of these vectors are connected and plotted, a segment of the spatial vectorcardiogram is obtained. ST segment data from leads X and Y are plotted on the frontal plane; similar data from leads X and Z are plotted on the horizontal plane; data from leads Y and Z are plotted on the sagittal plane. These three planar projections of spatial repolarization vectors intersect in 3-dimensional space and describe a spatial ST vector segment representing the 80 msec period of repolarization. Points along this segment, therefore, represent both the direction and magnitude of repolarization forces during this period of time. Since X, Y and Z coordinates of each spatial vector are known, shifts of the vectors in space can easily be computed for the various time periods of exercise and recovery.

Figure 16. Illustration of the derivation of the spatial ST segment.

An example of how the spatial ST segment shifts for a particular patient with coronary artery disease is shown in Figure 17. Three spatial ST vector segments representing the resting recumbent baseline, the 7th minute of exercise and the last (12th) minute of exercise are shown, along with the projections of these segments on the horizontal plane. The major shift that occurs is superior and rightward. The corresponding scalar electrocardiograms would show ST segment depression in both the X and Y leads.

Figure 17. Illustration of the spatial ST segment shifts in response to exercise for one particular patient with coronary artery disease.

RESULTS

In order to establish the normal range for the various scalar and vector quantities computed from the exercise ECG data, a group of 77 "normal" USAF flyers was studied and these data have been previously reported. These individuals were sent to the USAFSAM for evaluation of various noncardiac problems or for special evaluation prior to entering into test pilot programs. No evidence of cardiovascular disease was found after extensive non-invasive cardiovascular investigations. All of these subjects performed well on maximal treadmill testing and did not develop symptoms of heart disease during the test. The treadmill ECG data were recorded on analog tape and processed as previously described in the Methods. A variety of outputs were obtained following computer analysis. In addition to detailed numerical information describing the various scalar and vector parameters, plots of the averaged X, Y and Z data as well as spatial ST vector segments were obtained for each period of the baseline, exercise and recovery.

Since the phases of repolarization are influenced in an unequal manner by heart rate changes, the scalar and vector parameters that were computed in these normal subjects were grouped according to similar heart rates (± 5 beats/min) during exercise and recovery. Figure 18 illustrates the means and (-2 standard deviation limits for ST depression, ST-slope and ST-area from lead X at
Figure 18. Means and minus (-) two standard deviations for the measured parameters in bipolar lead X (CC5) in the normal subjects during exercise and recovery.

Figure 19. Computer generated plot of the 80 msec, spatial ST segment during exercise from normal subjects.

Forty-eight patients with angiographically proven coronary artery disease were studied in an attempt to correlate angiographic anatomy with computer measurements of exercise ECG data. These patients were subdivided according to their clinical symptoms and angiographic findings. Only six patients (13%) presented with symptoms of coronary artery disease, specifically angina pectoris. Each of these patients had obstructive lesions of 75% or greater in their major coronary arteries. The remaining 42 patients were all asymptomatic and were studied primarily because of electrocardiographic abnormalities detected by routine methodology. Twenty of these patients had obstructive coronary artery lesions of 75% or greater, 16 patients had 50-74% obstructive lesions, and 6 patients had less than 50% lesions.

The exercise ECG data from these patients with coronary artery disease were processed according to the methods described above. At each stage of the resting baseline, exercise and recovery, scalar and vector parameters were computed and compared to the normal range of values previously determined for the normal subjects. All comparisons were made at similar heart rates and body position. Computer printouts of the numerical information describing the ST-depression, ST-slope, ST-area, and vector coordinates were obtained for each patient. Measurements that were outside the ±2 standard deviation range established for the normal subjects were flagged and defined as significant abnormalities for this population. Using this definition, 44 patients (92%) had significant quantitative repolarization changes in lead X and/or Y occurring during and/or after the different heart rates achieved during exercise and recovery. The means are represented by "dots" while the (-2) standard deviation limits are noted by short horizontal bars. In general, the normal range for these parameters widened with increasing heart rates and were different for the recumbent and standing positions. In the recumbent (recovery) position, especially at higher heart rates, the ST segments were more elevated, the ST slopes were more positive (steeper), and the ST areas were more positive than the corresponding parameters in the standing (exercising) position. Occasionally, the normal range even included negative values which are thought to be representative of patients with coronary artery disease. Although not shown here, similar data defining the normal range of repolarization parameters computed from leads Y and Z were obtained and plotted.

The data from these normal subjects were also used to define the normal vector space occupied by the early repolarization forces for various heart rates during exercise and recovery. As was the case with the scalar parameters, the normal range of these repolarization vectors was obtained after the data had been grouped according to heart rate and body position. Means and standard deviations were then determined for each spatial ST vector along the 80 msec segment of repolarization. These vector parameters were expressed both numerically and graphically in terms of their x,y,z-coordinates. An example of a computer plot of the averaged vector data obtained from normal subjects in the standing (exercising) position at heart rates between 105 and 114 beats/min is shown in Figure 19. The heavy lines represent the averaged spatial vector segment along with the projections of this segment on the sagittal, frontal and horizontal planes. Segments representing ±2 standard deviations (thin lines) from the averaged segment are also projected on the three planes. Similar data for all heart rates during exercise and recovery have been computed for these normal subjects.
exercise. Three of the four patients who did not develop significant changes in any repolarization parameters had less than 50% occlusive lesions in their coronary arteries. The other patient had an isolated 90% lesion in a diagonal branch of the left anterior descending coronary artery.

Table 36 lists the mean values of those ECG measurements which were outside the ±2 standard deviation normal range along with the number of patients in each subgroup (in parentheses) having significant deviations in each parameter. For example, all six patients with angina pectoris had significant ST segment depression in lead X averaging (~0.27 millivolts; only three of six patients with less than 50% lesions on coronary angiography had significant ST segment depression in lead X, averaging ~0.14 millivolts. In general, the magnitude of the repolarization changes in lead X, as reflected by the depression, slope and area measurements, varied directly with the severity of coronary artery disease. Also the likelihood of any particular parameter exceeding the normal range varied directly with the severity of disease. Changes in the Y lead, although significant, did not seem to vary with the severity of the underlying coronary lesions in this group of patients.

An analysis of the spatial repolarization vectors computed from the coronary artery disease group of patients is also summarized in Table 36. All 20 patients with 75% or greater lesions had significant shifts of at least 60 msec of repolarization vectors outside the normal range. In contrast, only 12 of 16 patients with 50-74% lesions, and 2 of 6 patients with less than 50% lesions had significant spatial vector changes. In general, all significant changes were rightward and/or superior to the vector space defined for the normal subjects.

Five patients in this population with coronary artery disease had significant repolarization changes only during exercise and not in the recovery period. Two of these patients had 75% or greater lesions of their major coronary arteries, and three patients had 50-74% lesions. These significant changes would have been missed had the computer analysis been confined to the recovery ECG data alone.

One patient had significant changes confined to the Z lead alone. Coronary angiography revealed an isolated 50% obstructive lesion of the right coronary artery. Changes in the Z-lead were rarely found in patients with significant X and Y-lead abnormalities. The significance of Z-lead changes is unknown at the present time.

Eleven patients had isolated coronary artery lesions of at least 50% obstruction involving the right coronary artery or the left circumflex artery. No characteristic pattern of repolarization changes could be found which distinguished this group of patients from the seven patients with isolated significant lesions of the left anterior descending coronary artery. The spatial distribution of repolarization vectors was similar in both groups of patients.

**DISCUSSION**

The present study demonstrates both the feasibility and the desirability of automated analysis of the electrocardiographic response to exercise testing. It must be emphasized, however, that the current system for quantitating repolarization measurements is primarily a research effort and is not yet functioning as an operational tool. At this time, aeromedical recommendations are still being made on the basis of visual interpretation of the ECG data and cardiac catheterization findings. From this study, however, it is apparent that computer processing of exercise ECG data offers a number of advantages over conventional methods of interpretation.

The visual interpretation of exercise ECG data is frequently limited because of electrical noise or artifact, primarily occurring during exercise, but often present in the recovery period as well. Random high-frequency myoelectric noise generated by muscle potentials beneath the recording electrodes can easily be eliminated by digital averaging. It has been previously shown that most of the noise in exercise ECG data is random. Successful reduction of lower frequency baseline variations due to changing skin-electrode impedance has been more difficult. Careful skin preparation and proper choice of electrodes can keep this type of artifact to a minimum. Periodic electrical noise such as that due to inadequate grounding of equipment is managed by analog filtering of the ECG signals recorded on magnetic tape prior to analog-to-digital conversion. Thus, the use of analog and digital processing equipment can significantly improve the signal characteristics of exercise ECG data, thereby enabling more accurate and precise analysis of exercise induced changes.
The quantitative measurements of repolarization parameters from the average ECG data offer a new dimension in the analysis of exercise stress tests not previously achieved with conventional methods of interpretation. Visual analysis of ECG data, even without a significant noise component, is limited to only an estimation of the ST segment depression and slope. With the addition of myoelectric noise, baseline variation, and other types of artifact that accompany most exercise recordings, interpretation of ST segment configuration becomes most difficult. Because of this problem, it has been tempting to confine visual analysis to the postexercise ECG data where the noise component is minimal. In our patients with coronary artery disease, however, five (10%) had significant repolarization changes only during exercise, and all of these patients had lesions of 50% obstruction or greater. It is important, therefore, accurately to detect and monitor repolarization parameters during exercise as well as during the recovery period. Elimination of noise as previously discussed has enabled a more accurate analysis of the exercise data.

In addition to the advantages relating to noise reduction by computer processing of exercise ECG data, other benefits result from these techniques. The inter- and intra-observer variation inherent in visual interpretation of ECG data no longer is a significant impediment to accurate interpretation of the exercise electrocardiogram. Subjectivity is eliminated from the analysis. Each repolarization parameter is computed exactly the same way every time that parameter is measured. In addition to this consistency and uniformity in measurement, there is also enhanced precision in the measurements not possible with conventional visual methods.

Perhaps the most exciting and potentially rewarding advantage resulting from the application of computer technology to exercise electrocardiography is the ability to consider more sophisticated measures of repolarization that could not be considered with the visual interpretation techniques. In addition, ST depression and slope can now be measured more precisely, other parameters such as ST-area and ST vector segments can now be measured whereas they could not be measured before. There is no guarantee, however, that these new measures of repolarization will add increased sensitivity and specificity to exercise stress testing. Further studies are needed correlating the various computer derived repolarization parameters with angiographic anatomy. For each parameter or combination of parameters being considered the percent true positive and false negative (in patients with "known" coronary artery disease) as well as the percent true negative and false positive (in normal subjects) must be determined. These studies are now beginning at the USAFSAM.

The preliminary data presented in this report are encouraging but only represent a small population of patients.

Although the eventual success or failure of the computerized approach to quantitative exercise electrocardiography depends upon the determination of the sensitivity and specificity of the various "new" repolarization parameters, the present study was carried out only to demonstrate the feasibility of this approach. The 77 clinically normal subjects served to define the normal range for the various repolarization parameters under consideration. Since these patients did not undergo full hemodynamic and angiographic studies, it is quite possible that the data included some patients with subclinical disease. By considering only values outside the ±2 standard deviation range as "abnormal" values, it is unlikely that serious errors resulted when patients with coronary artery disease were studied. The present study, however, did not define new criteria for separating normal individuals from those with coronary artery disease; the study did demonstrate that patients with coronary artery disease almost always had repolarization changes outside the "normal range."

In order to eliminate the effects of heart rate on repolarization changes, data from an individual patient were always compared to that subgroup of the normal population having similar heart rates. In addition, the data were also compared at similar body positions, recumbent or standing, because of the changes in the normal range depending upon body position. In the population of patients with coronary artery disease, abnormalities in the computerized measurements were observed that would have been missed using the standard visual criteria of 0.1 millivolt or more horizontal ST segment depression. This was particularly true for lead X, where ST segment depression of less than 0.1 millivolt, often with a slightly positive ST slope, frequently fell outside the 2 standard deviation limits at certain heart rates. On the other hand, ST segment depression greater than 0.1 millivolt in lead Y often fell inside the normal range at certain heart rates and was, therefore, not interpreted as an abnormal finding. The Y lead was frequently noted to be more labile and to have a greater range of normal values than the other two leads.

It can be concluded that computer analysis of the electrocardiographic response to exercise is an important advance in the detection of early coronary artery disease. Much work remains to be done, however, before these techniques can be applied with ease to clinical testing. In this regard, efforts are currently being directed at developing on-line ECG processing using a minicomputer which will enable more practical clinical application. Additional data from normal subjects are being accumulated in order to better define the normal values at all heart rates for the various repolarization parameters. Also, other Y axis lead systems are being tested to see if lability can be reduced and if a better correlation with coronary artery lesions and with ST segment changes in standard leads II and aVF can be obtained. Finally, a major effort is underway to evaluate subjects with repolarization abnormalities who do not have angiographic coronary artery disease. In order to make the exercise test more specific, it is important to separate these individuals from those with coronary artery disease.
Section IV
CODING TECHNIQUES USED AT USAF SAM FOR TREADMILL RESPONSES AND CARDIAC CATHETERIZATION FINDINGS

In order to correlate the results of numerous tests performed on many individuals, it is essential to be able to simplify complex data by coding techniques. Codes make it possible to retrieve and analyze test results or other parameters in order to evaluate their significance.

USAF SAM Form 25 is used for recording the results of the Balke protocol maximal treadmill test performed on all referral subjects. All of the recorded data are later transferred to computer tape for retrieval and analysis.

<table>
<thead>
<tr>
<th>Page No.</th>
<th>14 TREADMILL EXERCISE TOLERANCE TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOCIAL SECURITY NUMBER</td>
<td>NAME (Last, First, MI)</td>
</tr>
<tr>
<td>DATE OF EXAMINATION</td>
<td>TEST RUN NUMBER</td>
</tr>
<tr>
<td>YEAR</td>
<td>MONTH</td>
</tr>
<tr>
<td>CONDITIONS</td>
<td>RECOVERY - SUPINE</td>
</tr>
<tr>
<td>TIME OF DAY</td>
<td>REASON FOR TERMINATING</td>
</tr>
<tr>
<td>ROOM TEMP (°F)</td>
<td>CHEST PAIN (Possible Angina)</td>
</tr>
<tr>
<td>HR SINCE LAST MEAL</td>
<td>RELATIVE HYPOTENSION</td>
</tr>
<tr>
<td>PB (mmHg)</td>
<td>ARRHYTHMIA</td>
</tr>
<tr>
<td>STPD FACTOR</td>
<td>ECG CODE</td>
</tr>
<tr>
<td>BELL READING</td>
<td>INHALED</td>
</tr>
<tr>
<td>SAMPLE VOLUME</td>
<td>MAXIMAL RQ</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>MINUTES</td>
</tr>
<tr>
<td>BODY FAT (%)</td>
<td>H.R.</td>
</tr>
<tr>
<td>MAXIMAL O₂ CONSUMED LAST MIN (L./MI)</td>
<td>VOLUME (L/min)</td>
</tr>
<tr>
<td>MAXAL O₂ CONSUMED (L)</td>
<td>O₂ (%)</td>
</tr>
<tr>
<td>MAXAL O₂ CONSUMED (cd/kg)</td>
<td>O₂ VOLUME (L/min)</td>
</tr>
<tr>
<td>CARDIAC WORK INDEX</td>
<td>RESPIRATORY DATA</td>
</tr>
<tr>
<td>BASELINE</td>
<td>SUPINE</td>
</tr>
<tr>
<td>TOTAL TIME (Min + Sec)</td>
<td>HYPERTENSION</td>
</tr>
<tr>
<td>MAXIMAL H.R.</td>
<td>EXHALED</td>
</tr>
<tr>
<td>O₂ CONSUMED (L)</td>
<td>O₂ VOLUME (L/min)</td>
</tr>
<tr>
<td>VOLUME (L/min)</td>
<td>O₂ (%)</td>
</tr>
<tr>
<td>DIL.</td>
<td>MAXIMAL RQ</td>
</tr>
<tr>
<td>DEUT. DIL.</td>
<td>MAXIMAL O₂</td>
</tr>
</tbody>
</table>

SAM FORM 25 SEP 73 PREVIOUS EDITION IS OBSOLETE
The data blocks in columns 1 through 8 are self-explanatory. Above column 9, activity status over the month prior to referral is coded as follows:

1 - The subject ran at least 10 miles a week or played three hours of a sport a week with an equivalent amount of running.
2 - The subject participated in vigorous exercise for at least 20 minutes two or three times a week that caused labored respiration and perspiration (golf, archery, calisthenics, bowling, weight lifting and yard work do not count).
3 - None of the above.

This activity status code makes it possible to correlate the effects of physical training on treadmill performance and aerobic capacity.

Column 9 (Findings) requires the following codes.

A. Interpretation

32x - Submaximal treadmill test (reason for submaximal effort given in column 7)
34x - Maximal effort treadmill test
0 - Normal
1 - Borderline because of .5mm to .9mm ST segment horizontal or downward depression/or inadequate ST slope (less than 1mv/sec.)
A - Borderline plus significant stress arrhythmia
B - Borderline plus symptoms suggestive of angina
2 - Abnormal because of 1 mm or more of horizontal or downward sloping ST depression
3 - Abnormal plus significant stress arrhythmia
4 - Abnormal plus symptoms suggestive of angina
7 - Normal ST response but with significant stress arrhythmia
9 - Other

"Significant stress arrhythmia" = ectopic beats that increase to frequent with exercise, three or more consecutive ectopic beats, or two consecutive ectopic beats plus others that increase with exercise.

"Frequent" = in any series of fifty beats, 20% or more are ectopics.

B. (Repolarization) and C. (Arrhythmia) subcolumns require the following three digit codes.

<table>
<thead>
<tr>
<th>1st digit</th>
<th>2nd digit</th>
<th>3rd digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

1st digit: Origin or leads of appearance

A - Supraventricular
B - Ventricular (unifocal or multiformed)
C - Ventricular (multifocal)
D - Mixed origin
E - Uncertain origin
X - X only (CC5)
Y - Y only
Z - Z only
V - Lateral precordial leads (V4, V5, V6)
L - I and/or V4, V5, V6
I - AVF and/or II
F - AVF/II and V
P - X, V4-6, and/or I
O - X, Y, and/or Z
R - Other combinations (Standard and/or bipolar)
K - Old "Y" lead
M - CM5
2nd digit: Time of appearance
R - Recumbent
H - Hyperventilation
U - Early standing
S - End of two-minute standing
E - Early exercise (three minutes or less)
M - Mid-exercise
L - Late exercise (last three minutes)
I - Immediate recovery
2, 3, ...8 - 2nd, 3rd, etc. minute of recovery respectively where abnormality first appears
A - Throughout pre-exercise periods
B - Mid-exercise and 5th or later minutes of recovery only
C - Progressing thru exercise and persisting thru immediate and later recovery
D - Late exercise and immediate recovery
F - Through mid and late exercise
G - Pre-exercise plus other periods without change
T - Late exercise and/or immediate recovery persisting into later recovery
J - Ectopic beats at rest or early exercise that decrease with exercise
K - Ectopic beats at rest or early exercise that increase with exercise

3rd digit: Manner of appearance
0 - Once
1 - Occasional
2 - Frequently
3 - Two ectopic beats consecutively only
4 - Three ectopic beats consecutively only
5 - Four or more ectopic beats consecutively only
6 - Two consecutive ectopics plus frequent other ectopics
7 - Three consecutive ectopics plus frequent other ectopics
8 - Four consecutive ectopics plus frequent other ectopics
9 - Other
A - T-wave inversion
B - ST straightening less than 0.5mm
C - J-Jct. depression of 1mm or more with Imv/sec. slope or less
D - J-Jct. depression with inadequate heart-rate adjusted slope
E - ST straightening or downward slope of 0.5mm to less than 1mm
F - ST straightening or downward slope of 1mm to less than 1mm
G - ST straightening or downward slope of 2mm or greater
H - One mm or more of ST segment coving
I - One mm or more of ST segment elevation
N - ST segment normalizing after being abnormal (if coded abnormal, time code for when ECG normalizes can be given)

D. ECG Code, other - Especially code infarction, WPW, BBB, rate dependent BBB, resting arrhythmias, repolarization abnormalities. Following is a shortened presentation of the extensive ECG code developed by Dr. Malcolm C. Lancaster.
### Major ECG Code Subdivision

<table>
<thead>
<tr>
<th>0xx - Rhythm</th>
<th>0xx - Rhythm Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x - Sinus</td>
<td>00x - Sinus</td>
</tr>
<tr>
<td>02x - Atrial</td>
<td>02x - Atrial</td>
</tr>
<tr>
<td>04x - Junctional</td>
<td>04x - Junctional</td>
</tr>
<tr>
<td>06x - Ventricular</td>
<td>06x - Ventricular</td>
</tr>
</tbody>
</table>

**0xx - Rhythm Origin**
- 00x - Sinus
- 02x - Atrial
- 04x - Junctional
- 06x - Ventricular

**0xx - Rhythm type**
- 0xl - Tachycardia
- 0x2 - Bradycardia
- 0x3 - Prematurity
- 0x4 - Escape
- 0x5 - Arrest
- 0x6 - Fibrillation

**00x - Sinus**
- 00A - Sinus
- 001 - Sinus tachycardia
- 002 - Sinus bradycardia

**02x - Atrial**
- 021 - PWT
- 023 - PAC
- 026 - Atrial fibrillation
- 027 - Atrial flutter

**06x - Ventricular**
- 061 - Ventricular tachycardia
- 063 - PVCs
- 065 - Asystole

**12x - Intraventricular Conduction**
- 120 - RBBB
- 121 - ICRBBB
- 122 - Intermittent RBBB
- 123 - Terminal conduction defect
- 124 - LBBB
- 125 - Intermittent LBBB
- 126 - IVCD

**70x - Miscellaneous**
- 700 - Normal ECG
- 702 - WPW, A
- 703 - WPW, B
- 705 - LGL (PR < .12 sec.)
- 706 - Pericarditis
- 715 - LVH with strain
- 729 - LVH voltage alone
- 735 - LAD

**2xx - Repolarization**
- 200 - Low amplitude T waves
- 201 - Nonspecific T wave changes
- 203 - Nonspecific ST depression
- 204 - Early repolarization
- 205 - ST segment straightening
- 215 - Prolonged QT interval
- 216 - Shortened QT interval
- 218 - History of serial ST and/or T wave changes

**6xx - Myocardial damage (location and criteria)**
- 60x - Inferior
- 61x - Anterior
- 62x - Posterior
- 63x - Lateral
- 69x - inferolateral

**6xx - Myocardial damage**
- 60x - Inferior
- 61x - Anterior
- 62x - Posterior
- 63x - Lateral
- 69x - inferolateral

**60x - Inferior**
- 6x0 - ST elevation

**61x - Anterior**
- 6x1 - ST depression

**62x - Posterior**
- 6x2 - T wave inversion

**63x - Lateral**
- 6x5 - Q wave

**69x - inferolateral**
- 6xB - History of

B, C and D have multiple three digit block columns so that multiple abnormalities can be coded. It is apparent that this system makes it possible to evaluate the significance of resting, hyperventilation or orthostatic repolarization changes in regard to exercise-induced repolarization changes. Also, various other patterns of ST segment response to exercise can be correlated with angiographic or epidemiological end-points for coronary artery disease.

The forms used to code the data gathered at cardiac catheterization and a description of the coding techniques are included. His bundle and hemodynamic data acquisition is rather straightforward. However, the coding of angiographic techniques and interpretation are more difficult and require detailed descriptions. Dr. A. J. Thompson has devised a relatively simple, well-defined, reproducible angiographic coding system with emphasis on left ventricular and coronary angiography. All coding systems have inherent limitations due to the inability to cover every possible anatomic variation and the author's bias and interests. The system as outlined is not only oriented towards grading obstructive coronary artery disease, but describes the coronary artery anatomy in general.
It is felt that too little attention has been paid to atrial arteries, ventricular epicardial vessels, unusual sources of collateral flow, and the diverse patterns of coronary artery branching patterns. Perhaps, most important is the use of defined nomenclature with explicit diagrams so that various angiographers can consistently locate, grade, and define arterial branches and their lesions.

CARDIAC CATHETERIZATION DATA

SECTION A: Patient Identification

1. Catheterization sequence number
2. Patient name (Last-First-MI)
3. Grade
4. SSAN
5. SAM case number
6. Date of Catheterization (day-month-year)
7. Nth. catheterization for this patient (1,2,3, etc.)

SECTION B: Clinical Data

8. Age (years)
9. Sex (M or F)
10. Height (inches)
11. Weight (lbs)
12. Body surface area (m²)
13. Percent body fat (%)
14. Serum cholesterol (mg%) 
15. Serum triglycerides (mg%)
16. Glucose tolerance test (N=normal, A=abnormal, I=incomplete)
17. Highest resting blood pressure (mmHg)
18. Three-day blood pressure average (mmHg)

SECTION C: Coronary Risk Profile

40. Has patient ever smoked cigarettes regularly (Y-N)?
   (if no, skip to item 45)
41. Is patient currently smoking cigarettes (Y-N)?
   (if no, skip to item 43)
42. Number of cigarettes currently smoked/day.
   (skip item 43)
43. If patient no longer smokes cigarettes, how long since quitting (Years)? Round to nearest year. Use zero if less than 6 months.
44. Number of years smoked times average number of packs per day (pack-years).
45. Has any of the patient's blood relatives had a heart attack, angina (heart related chest pain), coronary artery surgery, or died suddenly before the age of 65 years (Y-N)?
46. Has patient ever been told he has high blood pressure (Y-N)?
47. Current patient activity profile (enter number)
   1 - 10 miles of jogging per week or 3 hours of a sport.
   2 - 20 minutes of exercise 2 - 3 times per week.
   3 - No appreciable exercise.
48. Has patient exercised regularly at one time but no longer does so (Y-N)?
49. Does patient prefer and regularly eat meat with visible fat or skin (Y-N)?
50. Number of eggs eaten per week.
51. Does patient regularly eat (at least every other day) cheese or butter (Y-N)?

SECTION D: Referral Considerations

60-62. Reason(s) for SAM referral (one or more)
   1 - Flight Medicine
   2 - Psychiatry
   3 - Neurology
   4 - Ophthalmology
   5 - Internal Medicine
   6 - Cardiology
63-67. Clinical reason(s) for cardiac catheterization (one or more)
   1 - Abnormal electrocardiographic finding
   2 - Angina, definite or suspected
   3 - History of ischemic episodes or infarction
   4 - Mitral valve disease, suspected
   5 - Aortic valve disease, suspected
   6 - Cardiomyopathy, obstructive, suspected
   7 - Cardiomyopathy, non-obstructive, suspected
   8 - Pericardial disease, suspected
   9 - Risk factor profile suggestive of coronary heart disease

68-74. Electrocardiographic reason(s) for cardiac catheterization (one or more)
   1 - None, normal studies
   2 - Left bundle branch block
   3 - Right bundle branch block
   4 - Interventricular conduction defect
   5 - Supraventricular tachycardia
   6 - Atrioventricular block - 1st, 2nd, or 3rd degree
   7 - Serial T wave changes
   8 - Serial ST segment changes
   9 - Infarct patterns, ECG or VCG
   10 - Abnormal double Master's, referred with
   11 - Abnormal double Master's, SAM
   12 - Abnormal treadmill stress test with history of normal ECG's
   13 - Abnormal treadmill stress test with history of repolarization abnormalities
   14 - PVC's, VT - resting or exercise induced
   15 - Abnormal septal Q waves

SECTION E: Electrocardiographic and Treadmill Analysis

75-80. Resting fasting electrocardiogram (applicable SAM code(s))
81-86. Vectorcardiogram (applicable SAM Code(s))
87. Double Master's electrocardiogram (applicable SAM code)
88. Treadmill electrocardiogram (applicable SAM code)
89-92. Treadmill repolarization codes
93-95. Treadmill arrhythmia codes
96. Treadmill duration (minutes)
97. Maximal treadmill heart rate (beats/min)
98. Maximal treadmill oxygen consumption (cc/kg min)

SECTION F: Catheterization Procedures

99-107. Cath Procedures Used (one or more numbers)
   1 - Intravenous Catheter, Stand by
   2 - Intravenous Pacing Electrode, Stand by
   3 - Right Heart Catheterization
   4 - Left Heart Catheterization, Retrograde Brachial
   5 - Left Heart Catheterization, Retrograde Femoral
   6 - His Bundle Electrocardiography
   7 - His Bundle Electrocardiography with Atrial Pacing
   8 - Cardiac Output, Fick
   9 - Cardiac Output, Cardiogreen
10 - Coronary Sinus Metabolic Studies
11 - Supine Bicycle Ergometry
12 - Contractility Studies

108-113. Angiography Completed (one or more numbers)
   1 - Right Atrial Angiography
   2 - Pulmonary Angiography
   3 - Forward Angiography
   4 - Left Ventricle Angiography
   5 - Supravalvular, Aortography
   6 - Coronary Angiography, Sones
   7 - Coronary Angiography, Judkins
   8 - Coronary Angiography, Mixed
   9 - Right Ventricle Angiography

114-118. Catheterization Technique and Vessel Repair (enter appropriate number sequences)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>Antecubital Vein, R..1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Saphenous Vein, R ..2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Femoral Vein, R ..3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Brachial Artery, R ..4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Femoral Artery, R ..5</td>
<td>5</td>
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<tr>
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</tbody>
</table>
119-123. Complications of Cardiac Catheterization (one or more numbers)
1 - None
2 - Death
3 - Myocardial infarction
4 - Ventricular fibrillation
5 - Ventricular tachycardia
6 - Supraventricular tachycardia
7 - Atrioventricular block
8 - Asystole or marked bradycardia
9 - Any arrhythmia leading to discontinuation of the procedure
10 - Profound hypotension
11 - Intramyocardial injection
12 - Myocardial perforation
13 - Perforation of great vessels
14 - Diminished pulse
15 - Loss of pulse without symptoms
16 - Loss of pulse with symptoms
17 - Loss of pulse or arterial damage requiring surgical repair
18 - A-V Fistula
19 - Vasovagal reaction requiring treatment
20 - Complete heart block
21 - Serious allergic reaction
22 - Urticaria
23 -

124. Physician in Charge of Catheterization (enter number)
1 - Touchon
2 - Froelicher
3 - Thompson
4 - Rotman
5 - Triebwasser
6 - Schechter
7 - Longo
8 - Eades

SECTION G: Catheterization Hemodynamics

125. Aortic Pressure
126. Aortic Pressure (M)
127. Left Ventricular Pressure
128. End Diastolic Pressure (before angiography)
129. End Diastolic Pressure (after angiography)
130. Aortic Valve Gradient
131. Mitral Valve Gradient
132. Cardiac Index: L/min/M²

SECTION H: Supravalvular Aortography

133. Completed (Y or N)

134-138. (One or more by number)
1 - Normal
2 - Dilatation of aorta
3 - Aneurysm of aorta
4 - Dissection of aorta
5 - Unicuspid aortic valve
6 - Bicuspid aortic valve
7 - Aneurysm sinus valsalva
8 - Aortic regurgitation, Grade I
9 - Aortic regurgitation, Grade II
10 - Aortic regurgitation, Grade III
11 - Aortic regurgitation, Grade IV
12 - Aortic run off lesion, other
13 - Calcium, ascending aorta
14 - Calcium, aortic valve
15 -
16 -

SECTION I: Left Ventricular Angiography

139. Completed (Y or N)

140. Left ventricular angiogram (N=normal, A=abnormal)
(if A, complete items 141-146 and/or 147-152)
141-146. Location and definition of abnormal contraction patterns (select appropriate code(s))

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Anterior wall</td>
<td>1 - Akinesis</td>
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<td>2 - Apex</td>
<td>2 - Dyskinesis</td>
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<tr>
<td>3 - Diaphragmatic</td>
<td>3 - Hypokinesis</td>
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<tr>
<td>4 - Posterobasal</td>
<td>4 - Asynchrony</td>
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<tr>
<td>5 - Posterolateral</td>
<td></td>
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<tr>
<td>6 - Septal wall</td>
<td></td>
</tr>
</tbody>
</table>

147-152. Other left ventricular abnormalities

1 - Increased left ventricular wall thickness
2 - Thickened mitral valve
3 - Decreased motion mitral valve
4 - Billowing mitral leaflet, anterior
5 - Billowing mitral leaflet, posterior
6 - Mitral regurgitation, Grade I
7 - Mitral regurgitation, Grade II
8 - Mitral regurgitation, Grade III
9 - Mitral regurgitation, Grade IV
10 - Ventricular septal defect
11 - Calcium, mitral valve
12 - Calcium, mitral annulus
13 - Increased left ventricular size

SECTION J: Coronary Angiography

153. Completed (Y or N)
154. Coronary angiograms (N=normal, A=abnormal)

<table>
<thead>
<tr>
<th>Coronary Artery(ies) and Branches</th>
<th>Origin of the coronary artery (identify by segment letter(s))</th>
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</thead>
<tbody>
<tr>
<td>Sinus node artery - 1</td>
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<tr>
<td>Atrioventricular node artery - 2</td>
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</tr>
<tr>
<td>Left atrial circumflex - 3</td>
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</tr>
<tr>
<td>Right atrial circumflex - 4</td>
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<tr>
<td>Conus artery - 5</td>
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<tr>
<td>First diagonal branch of the LAD - D-1</td>
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</tr>
<tr>
<td>Second diagonal branch of the LAD - D-2</td>
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</tr>
<tr>
<td>Third diagonal branch of the LAD - D-3</td>
<td></td>
</tr>
<tr>
<td>First obtuse marginal branch of the L Cx - J-1</td>
<td></td>
</tr>
<tr>
<td>Second obtuse marginal branch of the L Cx - J-2</td>
<td></td>
</tr>
<tr>
<td>Third obtuse marginal branch of the L Cx - J-3</td>
<td></td>
</tr>
<tr>
<td>First right ventricular branch - Q-1</td>
<td></td>
</tr>
<tr>
<td>Second right ventricular branch - Q-2</td>
<td></td>
</tr>
<tr>
<td>Third right ventricular branch - Q-3</td>
<td></td>
</tr>
<tr>
<td>Intermediate coronary artery - M</td>
<td></td>
</tr>
</tbody>
</table>

159-174. Additional Anatomical Findings

175. Circulatory pattern

1 - Right dominant
2 - Balanced
3 - Left dominant

176. Origin of the posterior descending coronary artery(ies)

1 - Right coronary artery
2 - Left coronary artery
3 - Both
4 - Neither

177. Number of posterior descending branches (1, 2, 3, etc.)
178. Does the dominant posterior descending branch cross the crux of the heart (Y or N)?

179. Point of the LAD termination

1 - Anterior apex
2 - Posterior apex
3 - 1/4 way up the posterior interventricular groove
4 - 1/2 way up the posterior interventricular groove

180. Point of the true Cx termination

1 - Absent
2 - A-V groove
3 - Crux
4 - Beyond crux
181. Point of the RCA termination
1 - Before or at the acute margin
2 - Between the acute margin and crux
3 - Crux
4 - Beyond crux

182-183. Calcium (as visualized by fluoroscopy - identify location by appropriate letter(s) or number(s))

184-185. Myocardial bridging (as visualized by angiography - identify location by appropriate letter(s) or number(s))

186-187. Coronary spasm (as visualized by angiography - identify location by appropriate letter(s) or number(s))

188-204. Localization and grading of angiographic lesions (if present)
A - Diseased coronary artery branch or segment (identified by numbers or letters)
B - Lesion code - Thompson method (identified by number)
C - Lesion code - Sones method (identified by number)

205-212. Coronary collateral circulation (P=present, A=absent)
A - The coronary artery branch or segment from which the collateral channel originates (identify by number or letter)
B - Anastomotic channel (identify by number or letter)
C - Coronary artery branch or segment filled by collateral flow (identify by number or segment)

213-215. Coronary anomalies
1 - None
2 - Anomalies of the coronary ostia
3 - Anomalies of the coronary arterial distribution
4 - Other

SECTION K: Diagnosis

216-224.
1 - No evidence of organic heart disease
2 - No evidence of coronary artery disease
3 - Coronary artery disease, normal ventricular function
4 - Coronary artery disease, abnormal ventricular function
5 - Cardiomyopathy, obstructive (IHSS)
6 - Cardiomyopathy, non-obstructive
7 - Aortic valve disease, A.R.
8 - Aortic valve disease, A.S.
9 - Aortic valve disease, AR-AS
10 - Mitral valve disease, M.R.
11 - Mitral valve disease, M.S.
12 - Mitral valve disease, MR-MS
13 - Billowing mitral leaflet, anterior
14 - Billowing mitral leaflet, posterior
15 - Pericarditis, acute
16 - Pericardial effusion
17 - Pericarditis, chronic constructive
18 - Hypertensive cardiovascular disease
19 - Pulmonic Stenosis, valvular
20 - Pulmonic Stenosis, infundibular

SECTION L: Comments

DEFINITIONS FOR CODING OF CARDIAC CATHETERIZATION DATA

Supravalvular Aortography

The injection of contrast media into the ascending aorta is the definitive method in the diagnosis of aortic runoff lesions. The anatomy of the ascending aorta, aortic valve, and sinuses of valsalva are also well demonstrated by supravalvular aortography.
Aortic Regurgitation

Various means of grading or quantitating angiographic aortic regurgitation have been suggested. Most involve the injection of a minimum of 45 cc of contrast approximately 3 cm above the valve and studying the subsequent cardiac cycles.

Grade I - the systole immediately following the end of injection completely clears the regurgitant contrast.

Grade II - the regurgitant contrast is not completely cleared by the systole immediately following the injection.

Grade III - there is progressive accumulation of contrast during several cardiac cycles which may lead to complete opacification of the ventricle.

Grade IV - the regurgitant contrast completely opacifies the ventricle at the end of the first diastole.

Left Ventricular Angiography

Mitral Regurgitation

Left ventricular angiography is the definitive means for diagnosing mitral regurgitation. Irrespective of the etiological basis of the mitral regurgitation, the degree can be reasonably well quantitated as follows:

Grade I - there is a regurgitant jet with minimal staining of the left atrium which clears rapidly.

Grade II - there is a regurgitant jet with moderate opacification of the left atrium which tends to clear rapidly.

Grade III - the left atrium is opacified as intensely as the left ventricle and aorta on the late films. The radiopaque medium clears slowly from the left atrium. No jet is seen. The left atrium is usually, although not always, greatly enlarged.

Grade IV - the left atrium is more densely opacified than the left ventricle or aorta. The left atrium is usually markedly enlarged and the left ventricle dilated. The left atrium remains intensely opacified through the entire series of films.

Synergy and Dyssnergy

The normal left ventricular contraction pattern is readily defined as a uniform almost concentric inward motion of all points along the ventricular inner surface during systolic ejection (synergic pattern).

Dyssnergy (Asynergy) is the lack of a coordinated, uniform left ventricular contraction pattern. There are four distinct types of dyssnergy:

- Akinesis - a total lack of motion of a portion of the left ventricular wall.
- Dyskinesis - (paradoxical) - systolic expansion (or bulge) of a region of the left ventricular wall.
- Hypokinesis (Asyneresis) - diminished or inadequate motion of part of the ventricular wall.
- Asynchrony - a disturbed temporal-sequence of contraction.

The various types of dyssnergy can involve any portion of the left ventricular wall.

Anatomic Classification of Coronary Artery Circulation

The principle of dominance relates only to the anatomic distribution of the coronary arteries. As judged by coronary blood flow, the left coronary artery (LCA) is always the dominant artery. The criteria used for classifying coronary artery patterns as being right dominant, balanced or left dominant are given below.

Right Dominant Circulation (Fig. 20)

The right coronary artery (RCA) supplies blood to a large part of the posterior wall of the left ventricle. In addition, the posterior descending artery arises from the RCA. A useful guide is to note which artery (RCA or LCA) crosses the crux of the heart. The right dominant coronary artery always traverses the crux and turns as the posterior descending into the posterior interventricular sulcus. In summary, it is considered right dominant because the RCA supplies all of the right ventricle, the posterior half of the interventricular septum, and part of the left ventricle.
Figure 20. Postmortem angiogram of a heart with a right dominant circulatory pattern. Note that the RCA supplies left ventricular branches as well as the posterior descending branch.
Balanced Circulation (Fig. 21)

Each of the heart's two ventricles receives its entire blood supply from the correspondingly named coronary artery. The RCA has no significant branches extending to the posterior half of the LV and the circumflex has no branches traversing the posterior interventricular sulcus. Here the RCA supplies only the right ventricle plus the posterior half of the interventricular septum and the LCA supplies the left ventricle plus the anterior part of the interventricular septum. Both coronary arteries give off posterior descending branches.

Figure 21. Postmortem angiogram of a heart with a balanced circulation. Each coronary artery supplies its respective ventricle. The posterior descending branch of the RCA supplies the posterior half of the interventricular sulcus while the posterior descending branch of the left circumflex and the distal LAD supply the anterior interventricular sulcus.
Left Dominant Circulation (Fig. 22)

The circumflex continues in the coronary sulcus, passes across the entire anterior and posterior surface of the left side of the heart to reach the posterior interventricular sulcus, turns down the sulcus and courses towards the apex. The circumflex artery traverses the crux of the heart and as it turns into the posterior interventricular sulcus, it becomes the posterior descending (circumflex posterior descending).

Figure 22. Postmortem angiograms of a heart with a left dominant circulatory pattern. The small RCA barely reaches the acute margin of the heart while the LCA traverses the crux giving off posterior descending branches in the posterior interventricular sulcus.
Segments and Branches of the Left Coronary Artery (Fig. 23)

Ao--Aortic root.

A--Ostium of the left coronary artery.

B--Left main coronary artery. The LCA proximal to the bifurcation of the anterior descending and circumflex coronary artery.

C--Proximal portion of the left anterior descending (LAD) coronary artery. Distal to the bifurcation and proximal to the first penetrating septal branch of the LAD.

D--Diagonal branches of the LCA. The diagonals are muscular branches to the anterior free wall of the left ventricle. They arise from the LAD coronary artery and vary in number and size. They are designated as D-1, D-2, D-3.

E--First septal perforating branch of the LAD.

F, G, and H--The remainder of the LAD coronary artery is divided as follows.
  F - the area distal to the first penetrating septal branch and halfway to the apex.
  G - the segment of the LAD from the end of segment E to the apex.
  H - the distal LAD from the apex of the heart to its termination.

I--Proximal portion of the circumflex coronary artery beginning at the bifurcation and ending as it turns into the atrio-ventricular (AV) groove becoming the true circumflex.

J--Obtuse marginal branches of the left circumflex (circumflex marginals). One or more branches from the circumflex may descend towards the left ventricular apex. These are designated as J-1, J-2, J-3.

Figure 23. Schematic diagram of the left coronary artery in the right anterior oblique projection. Labeling and segmenting of the artery has been accomplished. The artery is drawn to show a left dominant circulatory pattern.
K—The portion of the left circumflex coronary artery that lies in the A-V groove (true circumflex) but proximal to the crux and posterior descending (PD, circumflex posterior descending) branch.

L—Posterior descending branch of the left circumflex (circumflex posterior descending). The branch traveling in the posterior interventricular groove. If there are two branches traversing the posterior interventricular sulcus, the designation of L-1, L-2 will be employed.

M—Intermediate coronary artery. The intermediate coronary artery is the third branch of the LCA which arises at the bifurcation of the LAD and left circumflex coronary artery forming a trifurcation. The following nomenclature will be used for vessels forming a near trifurcation but definitely separated from the bifurcation. If the vessel clearly arises from the LAD, it will be designated as a diagonal; if it arises from the left circumflex, it will be designated as an obtuse marginal.

Segments and Branches of the Right Coronary Artery (Fig. 24)

Ao—Aortic root.

N—Ostia of the right coronary.

O—Proximal portion of the RCA. The portion of the proximal RCA from the ostium to just distal to the sinus node artery. If the sinus node artery arises from the proximal circumflex, the distal boundary is the conus branch of the RCA. If neither are present, the distal boundary is considered to be 3 cm from the ostia.

P—The portion of the RCA distal to the sinus node artery or conus branch of the RCA and proximal to the acute margin of the heart.

Q—Right ventricular branches of the RCA. These muscular branches course anteriorly and supply the right ventricular myocardium. These may be multiple and will be designated as Q-1, Q-2, Q-3, etc.

R—Acute marginal branch of the RCA. Descends along the acute margin towards the apex and terminates in small branches in the lower third of the ventricle.

S—The portion of the RCA distal to the acute margin of the heart and proximal to the posterior descending branch of the RCA.

T—Posterior descending branch of the RCA. The branch which travels in the posterior interventricular groove toward the distal LAD. Occasionally, more than one vessel will follow the interventricular septum giving off septal perforators. When this occurs, the designation of T-1, T-2 is used.

U—Left ventricle branches usually originate from the vessel crossing the crux. They are highly variable and may be absent. They are absent when there is a left dominant circulatory pattern.

Special Arteries of the Coronary Tree (Figs. 23 and 24)

1—Sinus node artery
2—A-V nodal artery
3—Left atrial circumflex
4—Right atrial branch
5—Conus branch or pulmonary conus branch

Grading of Coronary Arteriographic Lesions

Each angiographic lesion found in the RCA and LCA is graded according to the approximate percent of narrowing. The scoring is as follows:

0—Normal, no arteriographic abnormality seen.
1—Less than 10% narrowing - trivial irregularity of minimal intimal roughening.
2—Significantly less than 50% narrowing.
3—Approximately 50% narrowing.
4—Significantly greater than 50% narrowing.
5—Near total occlusion.
6—Total occlusion.

Each lesion is located and identified by segment letter and graded as above. If the lesion is greater than 1 cm in total length, a "plus" will be added to the above grade.
RIGHT CORONARY ARTERY - LEFT ANTERIOR OBLIQUE

Figure 24. Schematic diagram of the right coronary artery in the left anterior oblique projection. Labeling of branches and segments is demonstrated. This right coronary artery is drawn to reveal a right dominant circulatory pattern.

The above is an arbitrary grading system based on approximate percent narrowing. This is a realistic method of grading coronary arteriograms in which accurate and consistent classification is possible. In order to semi-quantitate the extent of coronary atherosclerosis, each lesion is graded and scored. The scores from each segment may be totaled giving an indication of the total degree of atherosclerotic involvement.

In addition to our own favored method of grading coronary arteriographic lesions, each lesion will be scored according to the method of Sones. This will allow us to compare our results with and utilize his prognostic curves based on large numbers of patients.

0—Normal - Smooth walled vessel without variations in luminal diameter 1—Mild Narrowing - Narrowing up to 30% of diameter 2—Moderate Narrowing - Narrowing greater than 30% and less than 50% 3—Moderately severe obstruction - 50% to 90% narrowing 4—Subtotal obstruction - 90% to almost total obstruction 5—Total obstruction

General Discussion of Anastomotic Channels

Transatrial - the atrial coronary circulation is an ideal route for collateral flow. Most atrial arteries are epicardial and subject to less intramyocardial compression. The two atria are located directly above the main portion of the RCA and the left circumflex artery providing a potential route of communication between these major trunks. Transatrial anastomoses, while simple to demonstrate in the postmortem heart, are not well visualized or recognized by coronary arteriography.
Trans-septal - anastomoses through the ventricular septa can connect the two major coronary vessels occupying the anterior and posterior interventricular sulci. The anastomoses within the interventricular septum have long been recognized as major routes for collateral circulation between the left anterior descending and posterior descending arteries.

Ventricular Epicardial Anastomoses - coronary arteriographic and postmortem studies frequently reveal extensive intercoronary anastomoses on the ventricular epicardium. Following occlusion of either the RCA or LAD artery, the intercoronary anastomoses between these two vessels across the free wall of the right ventricle are easily visualized with angiography. Intercoronary anastomoses between branches of the LAD and circumflex arteries across the free wall of the interventricular wall or between the left circumflex and terminal RCA on the diaphragmatic surface of the heart are more difficult to demonstrate angiographically but regularly exist. Two points make the ventricular epicardial anastomoses important: 1) they connect the major arteries; 2) they are not subject to normal myocardial systolic compression.

Anastomoses via Special Arteries - include the conus artery or the conal branch of the RCA; the sinus node artery; the A-V nodal artery and Kugel's artery. Kugel's artery originates near the aorta from either the proximal RCA or LCA (occasionally both) and courses directly into the anterior margin of the atrial septum and then posteriorly. It thus forms potential connections between the most proximal portion of either main coronary artery and the circulation of the diaphragmatic surface of both ventricles by way of the A-V node and His bundle. Kugel's artery is extremely difficult to visualize with coronary arteriogram in vivo and is not simple to demonstrate postmortem. The fact that it does not enlarge to easily demonstrable size suggests that, despite its critically valuable location, it may not be a major route for a large volume of coronary collateral circulation. However, its proximity to the A-V node and His bundle makes it of good potential value for collateral circulation to those critically important structures.

Coronary Collateral Circulation

The presence of coronary collateral circulation is confirmed by: (1) Opacification of a coronary artery after the injection of radiopaque dye into the contralateral vessel; (2) Visualization of a segment of an artery distal to its complete occlusion after injection of contrast proximal to the occlusion; and (3) Direct visualization of accessory blood vessels either filling the distal segment of an occluded or severely stenotic artery or subserving an area of myocardium distal to an occluded or severely stenotic vessel.

Intracoronary (Homocollaterals) - an anastomatic channel connecting one part of a coronary artery to another segment of the same artery. They are usually short anastomoses and are most often vasovasorum or adventitial arteries. They may form a multichannel cuff around the narrowing or occlusion and on arteriogram gives a characteristic "starburst" appearance.

Intercoronary (Heterocollaterals) - an anastomosis which connects two separate arteries. This usually refers to direct connections between two separate major trunks such as the proximal RCA and the LAD artery. Under the new stress of pressure, the normally thin-walled anastomoses becomes elongated and twisted, so that this altered appearance is a crude but reliable index of the presence of function by the anastomoses for the purpose of collateral flow.

Anomalies of Coronary Anatomy

The incidence of coronary arterial anomalies in large general hospital studies has been shown to be approximately 2.85 per thousand. Anomalies of the coronary arteries largely fall into two categories: 1) anomalies of the coronary ostia and 2) anomalies of the coronary arterial distribution. A review of the literature reveals that other congenital cardiovascular defects are extremely common in cases of anomalies involving the coronary ostia. Anomalies involving coronary arterial distribution do not seem to be associated with an increased incidence of other cardiac anomalies. Thus, anomalies of the coronary ostia are of greater practical significance by far than those of coronary arterial distribution.

The coronary arteries are subject to considerable anatomic variation. For the most part, the variations consist of irregularities of the peripheral distribution of the vessels so that either the right or left artery supplies a greater portion of the myocardium. The presence of a single coronary artery or an anomalous origin of one of the major branches, on the other hand, is sufficiently uncommon to be of interest.

1—Anomalies of the Coronary Ostia: common ostia, R or L sinus, separate ostia in one sinus, R or L; absent ostia, R or L; separate ostia for circumflex; multiple ostia, R or L sinus; ostia arising above sinus, R, L, or both; coronary artery(ies) originate from the pulmonary artery.
2—Anomalies of the Coronary Arterial Distribution: rudimentary RCA; circumflex, a branch of the RCA; rudimentary L circumflex.

3—Other: Coronary artery aneurysm; arteriovenous communications.

*A rudimentary RCA will be coded as an anomaly only if the terminal portion of the RCA does not reach the margo acutus.

+A rudimentary circumflex will be coded if the circumflex branch of the LCA fails to enter the atrioventricular groove.

ACKNOWLEDGEMENT:

The authors acknowledge the assistance of our co-workers in the Clinical Sciences Division, and the support of the Biometrics Branch, Medical Editing, and Medical Illustrations. We also thank Mrs. Rosa Linda Rodriguez for her patience in typing the many drafts of this manuscript.
BIBLIOGRAPHY


Additional references


Coronary heart disease (CHD) has reached epidemic proportions in all developed countries; it accounts for over 1,000,000 deaths in the United States each year, which is more than all other diseases combined. Over half of these deaths are unexpected in that they occur without preceding symptoms of CHD. Despite the selective nature of the USAF flying population, CHD is the leading disease cause of death, disability and removal from flying duties. It appears that USAF aircrewmen very well fit the national statistics. Because of the critical nature of flying duties and the pertinence of flying safety, the early detection of CHD is essential in the USAF flying population.

This AGARDograph presents the experience of the United States Air Force School of Aerospace Medicine (USAFSAM) in the use of treadmill exercises for evaluating asymptomatic aircrewmen. It consists of separate studies involving different aspects of treadmill testing experience at the USAFSAM, including descriptions of techniques used at the USAFSAM.

This AGARDograph was sponsored by the Aerospace Medical Panel of AGARD.
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