PHYSICAL ACTIVITY AND THE PREVENTION OF CORONARY HEART DISEASE*

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IN the course of evaluating new approaches to the prevention of a disease, their acceptance generally can be characterized as evolving through three levels: the possibly beneficial, the prudent, and the proved. It is our thesis that the value of physical activity as a preventive approach to coronary heart disease (CHD) today is widely accepted as being both possibly beneficial and prudent and that we now are in the research stage where we must prove or disprove the efficacy of this approach.

Certainly the value of physical activity as a beneficial means of preserving and enhancing health and total human performance long has had many advocates, who stretch back to the ancient philosophers, among them Plato, who said: "Lack of activity destroys the good condition of every human being while movement and methodical physical exercise save it and preserve it." At the same time there also are those who have been less inclined to espouse the benefits of exercise, not the least of whom is Robert M. Hutchins, who is alleged to have said: "Whenever I feel like exercise, I lie down until the feeling goes away."

POPULATION STUDIES

As Charles W. Frank has pointed out earlier in this conference, the first studies to demonstrate a statistically significant relation between physicial activity and CHD were those conducted by J. Morris and his

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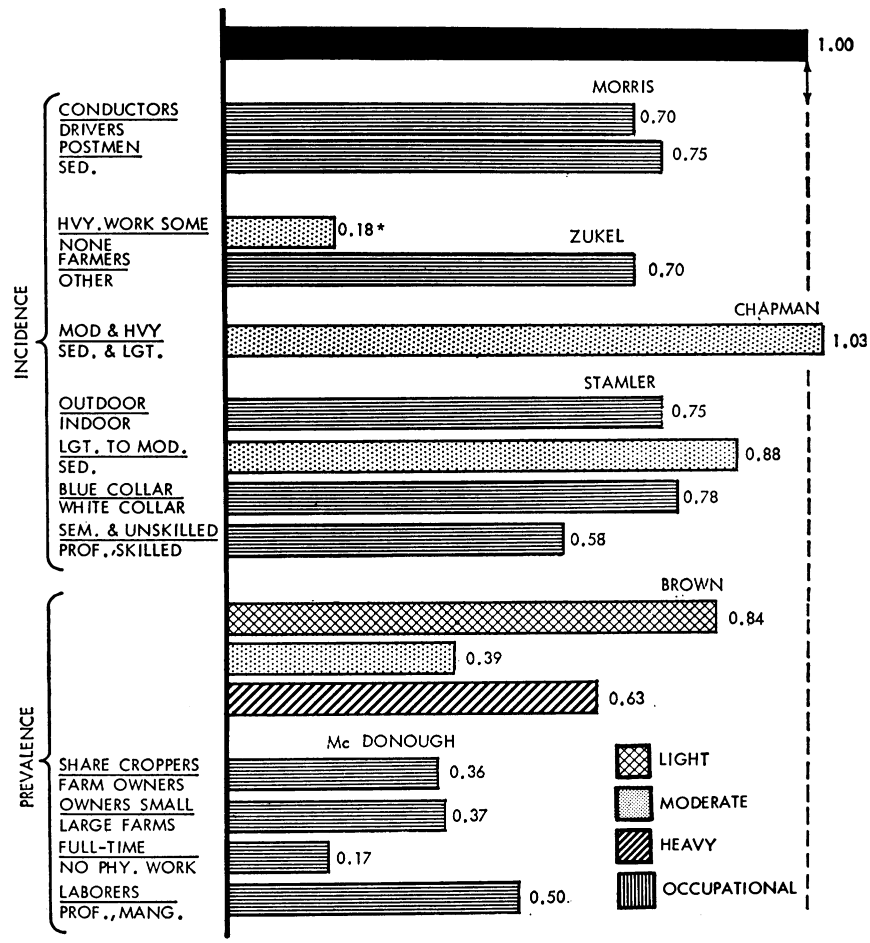

* FROM FURTHER ANALYSIS OF DATA

Fig. 1. Total coronary heart disease. Persons classified according to presumed level of physical activity. Figures 1, 3, 4, 5, and 6 are reproduced by permission from: Fox, S. M. III and Haskell, W. L., Population studies. *Canad. Med. Ass. J. 96*:806, 1967.

colleagues in London early in the 1950's.[1] Dr. Morris' findings are indicated in Figure 1, which reviews data on the incidence and prevalence of all forms of CHD from the studies known to us on this subject. Morris found that London bus conductors had only 73 per cent the frequency of CHD that was found in the presumably less active bus drivers. His later comparison of London postmen and less active postal clerks produced much the same findings.[2]

In reviewing data of this nature, of course, we must be careful to

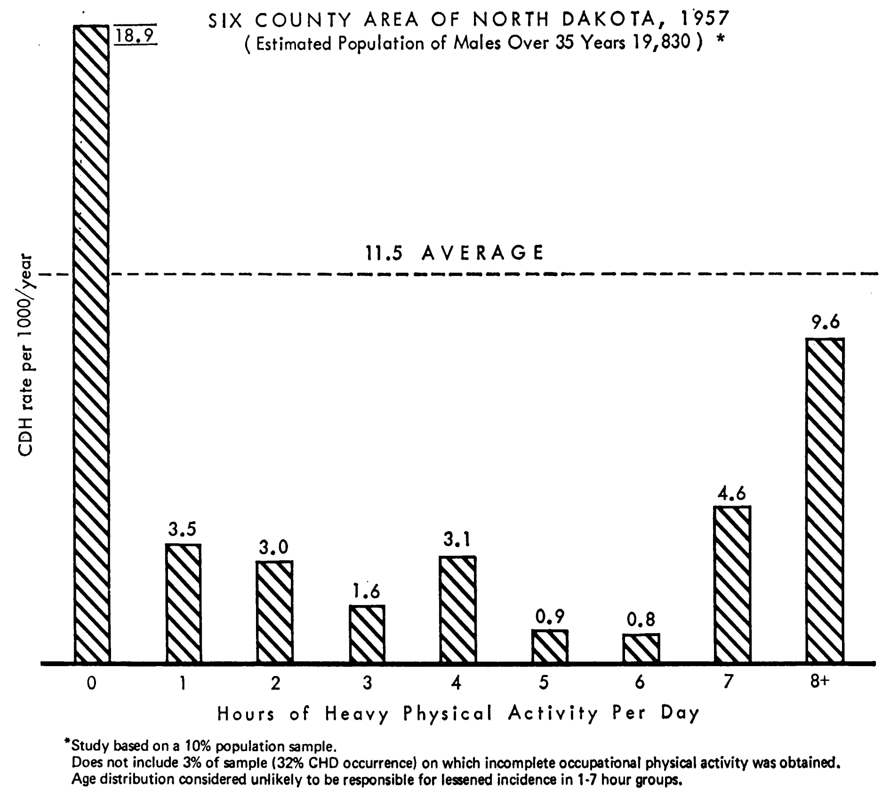

Fig. 2. Incidence of coronary heart disease by hours of heavy physical activity at usual occupation.

distinguish between associative and causal relations. It remains to be proved that members of groups that have different levels of occupational or other physical activity are sufficiently comparable in other important respects to support the assumption of a causal relation. Occupations of differing activity levels may be chosen because of personal selection factors or be assigned to or chosen *for* individuals by circumstances of skill, ability, aptitude, and interest.

Let us return to Figure 1. In 1956 Morris and his colleagues[3] published another study, interestingly titled, "Physique of London Busmen, the Epidemiology of Uniforms." This investigation, based on records of measurements of uniforms, indicated that the bus drivers were taller and proportionately heavier than conductors on entry into service. This finding has interest in light of the association between overweight, high blood pressure, serum lipids, and CHD on which Morris has reported.[4]

In a study by Zukel in North Dakota in the late 1950's, a striking difference was shown to exist between persons performing "heavy" work and those doing almost no physical work.[5] Later analysis of Zukel's data showed that persons doing from one to two hours of heavy physical activity a day had only 18 per cent the incidence of those working less than one hour (Figure 2).[6] Zukel's study also found the incidence of more severe CHD among farmers to be 70 per cent of that of other less active occupational groups.

In Chapman's study we see a departure from the general trend observed throughout the other data.[7] In his observations on civil servants in Los Angeles Chapman found no occupational difference in either total CHD or CHD mortality. While no ready explanation exists for these anomalous findings some have said that no civil servants, *anywhere*, whatever their occupational classification, are physically active! As government servants, we reject this! Others say that in the sunny climes of California all persons are so active off the job with their swimming pools, surfing, and golf that the occupational classification alone is not significant. We hasten to add that we have no data to offer in either regard.

Stamler's data on Chicago utility workers show a consistently lower incidence among the presumably more physically active, although the differences are not at a high level of statistical significance.[8] Studying a group of elderly patients in Birmingham, England, in relation to their previous occupation, Brown found that the more active individuals had the more favorable status in terms of CHD prevalence.[9] McDonough, in an investigation of a biracial community in Georgia, found a marked difference in CHD incidence between the more active sharecroppers on small farms and the less active proprietary managers of large farms.[10]

From these studies we can see a strong tendency implying the benefit of increased physical activity in relation to total CHD. However, as Frederick H. Epstein has observed, particularly in relation to Morris' more recent work, it may be that the cholesterol and blood-pressure levels are significant contributing factors. Thus the question remains: Is the major element "something" that is a result of physical activity? Does physical activity, either occupationally-related or otherwise, modify blood pressure and reduce cholesterol? We should like to have more data in this regard.

Figure 3, which concerns incidence and prevalence of myocardial infarction, indicates that Morris' conductors had 53 per cent the inci-

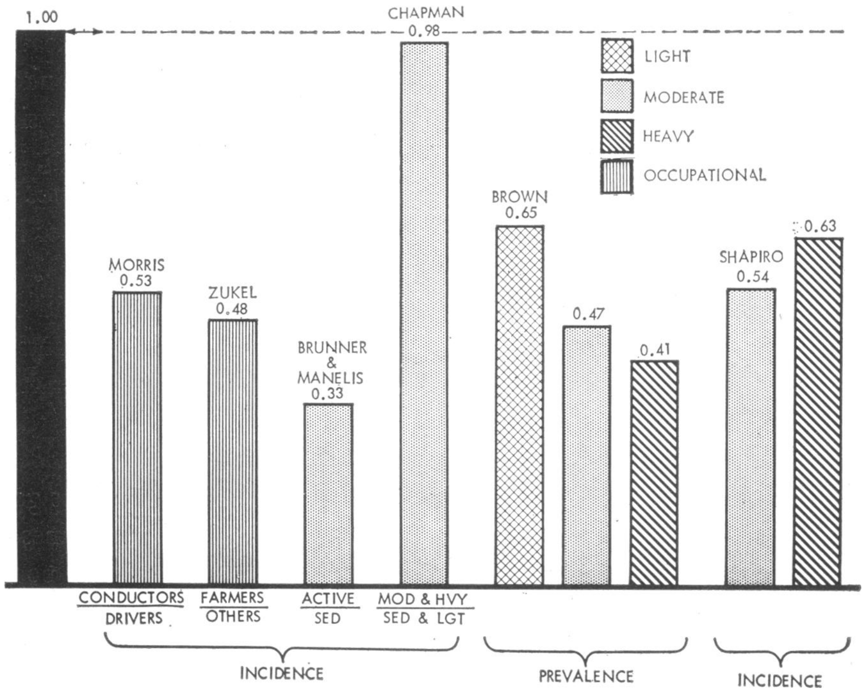

Fig. 3. Myocardial infarction. Persons classified according to presumed level of physical activity.

dence of the bus drivers. The farm workers in Zukel's study had an incidence of myocardial infarction only 48 per cent that of other occupational groups. Comparing active and sedentary members of Israeli kibbutzim, in which everyone's diet is likely to be essentially the same, Brunner and Manelis found the incidence of myocardial infarction among the "actives" to be one third that of the less active.[11]

Here again, Chapman's study stands out as the exception. Brown's data on the prevalence of myocardial infarction are similar to his total CHD statistics. Shapiro's findings,[12] updated by Frank,[13] indicate the same relative pattern: the least active experienced about twice the incidence of first infarctions compared to the intermediate and most active individuals.

Figure 4 contains data on CHD mortality. With regard to Morris' London studies, we see a marked reduction in favor of the conductors compared to drivers, and of postmen compared to the more sedentary clerks. The difference between the two groups relative to mortality is greater than it was for total CHD or myocardial infarctions.

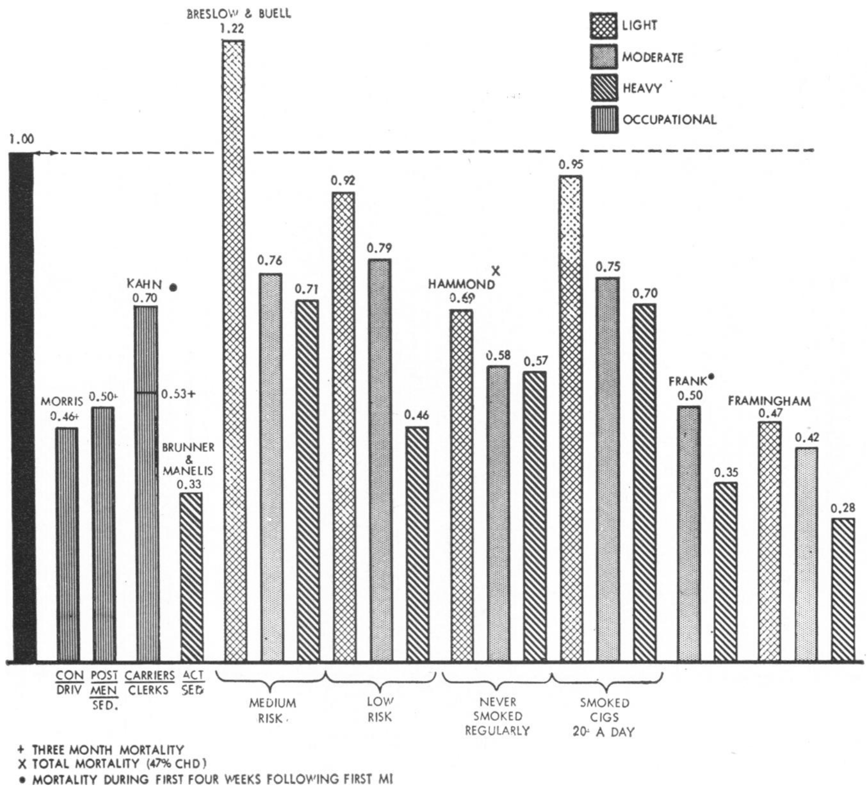

Fig. 4. CHD mortality. Persons classified according to presumed level of physical activity.

Kahn's study of postmen in Washington, D. C. produced results similar to Morris' findings for postal carriers and clerks in England.[14] When the gross figure, which indicates the postal delivery men, is adjusted as a result of transfers of persons between the two categories of employment, the figure is reduced to 53 per cent, very near Morris' results.

Kahn suspected there was a relatively small increment of caloric expenditure in the work of mail delivery. The number of hours actually involved was not great, there was little requirement for going up flights of steps, and the pushing and carrying of heavy mail bags had largely been eliminated from mail delivery. Kahn also stated that recent activity was relevant, not that of earlier years.

The results of Brunner's Israel study in terms of CHD mortality correspond closely to his findings on mortality from myocardial infarction.

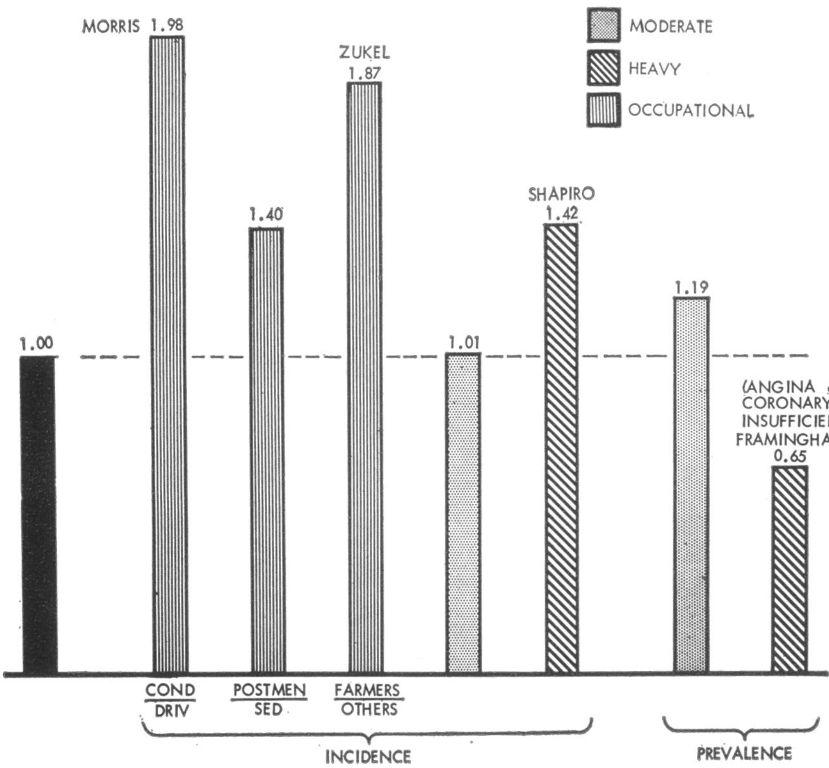

Fig. 5. Angina pectoris. Persons classified according to presumed levels of physical activity.

Breslow and Buell performed a complex study in California that involved adjusting for "general health risk" in statistics analyzed according to occupation.[15] Unadjusted, the data did not indicate an association between physical activity and CHD mortality. With the adjustment, the mortality trends favored the more active individuals.

Hammond undertook one of the new projects that concern non-occupational physical activity.[16] The figures shown here relate to overall mortality, but for both smokers and nonsmokers CHD represented 47 per cent of all deaths. Hammond recorded the exercise habits of those who had never smoked and those who smoked 20 cigarettes or more each day. He found that among nonsmokers even light activity was associated with a lower mortality than among the sedentary; however, for "heavy" smokers, the equivalent mortality was associated only with those who engaged in "heavy" exercise.

This can be considered to imply that in order to gain the benefits of physical activity, the steady cigarette smoker must compensate for his habit by performing much more physical activity than the nonsmoker.

Figure 5 relates the interesting enigma concerning the relation of physical activity to angina pectoris. Many of the studies indicate that angina is found more frequently in those who are more active physically. This was the case in Morris' study, although to a lesser extent in the postmen-clerk relation than in conductors vs. drivers. Zukel's data also shows an almost twofold increased incidence of angina in farmers as compared to other occupations. To a somewhat lesser extent, the same finding was made by Shapiro.

The only published exception to this trend is found in Kannel's Framingham data,[17] although we understand that the further data of Dr. Frank's study of the Health Insurance Plan of Greater New York are of a similar nature.

There is no evidence to support the hypothesis that the increased activity of more active individuals brings on anginal symptoms. Nor can it be verified that those who exhibit increased angina would be in another more severe category, or dead, were it not for the protective adaptation produced by the stimulus of physical exertion.

We might mention briefly the studies Karvonen,[18], Montoye,[19] Pomeroy and White,[20] and others have made on the relation of CHD mortality to participation in athletics and sports. One of the more interesting findings has been the observation of a lower mortality rate for college athletes who remain more active in their later life than for their sedentary counterparts. Nevertheless the factors of selection bearing on the determination of who becomes an athlete, and particularly a long-term, "life-long" athlete, are of such significance that a detailed review of the subject does not seem justified in the time available.

Studies in Pathology

Next we should turn to the pathology of CHD and the data of Morris and Crawford shown in Figure 6.[21] By collaboration of 206 hospitals in the United Kingdom, postmortems were made of the hearts of men aged 45 to 70 and categorized as having engaged in light, active, or heavy physical activity in the stated occupations not considered to be influenced by terminal illness.

Large fibrous patches were found less frequently in the hearts of those who were presumably most active. Those in the middle range of

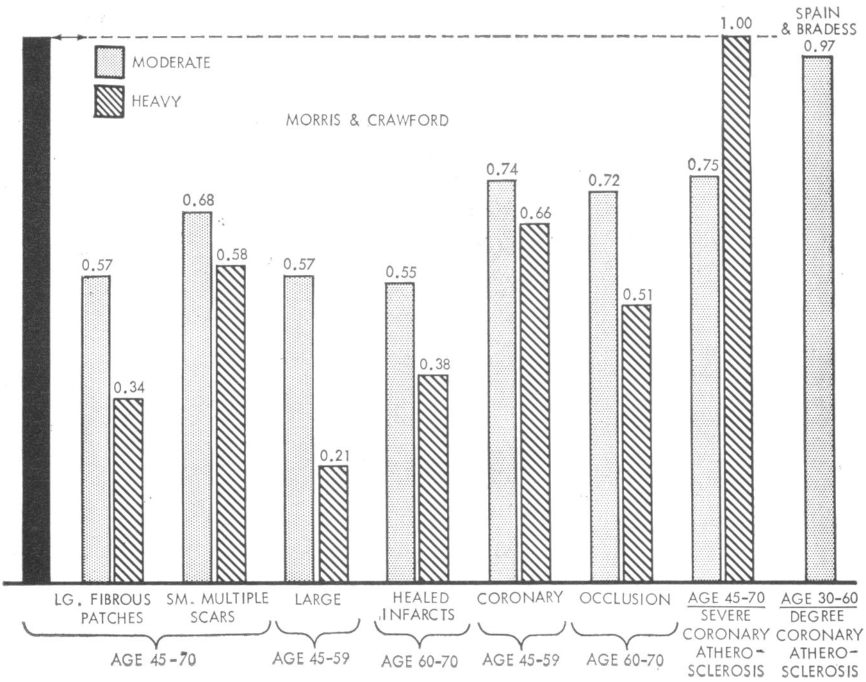

Fig. 6. Coronary heart disease pathology. Persons classified according to presumed level of physical activity.

activity had an intermediate number of patches. In persons of this same age small multiple scars also were found to occur more in the moderately active than in the heavily active, although the difference is not as great as in the case of the fibrous patches. The same relation of heavy to moderate activity holds for large healed infarcts in persons aged 45 to 59 and 60 to 70.

Careful examination of the data shows that those who engaged in heavy activity—the boilermaker-manufacturing type of activity—had a rather increased incidence, which indicates that there may be a limit beyond which this beneficial association does not continue.

Figure 6 also presents the results of Morris and Crawford's study in terms of coronary occlusion. Here the difference is somewhat less than in the case of the patches and scars, although the difference is still sizable; also of interest is the more marked difference in the older group.

Morris and Crawford made an attempt in this study to avoid the influence of situations in which individuals had listed as "light-activity" occupations that resulted from migration from heavier activity because

TABLE.—MECHANISMS BY WHICH PHYSICAL ACTIVITY MAY REDUCE THE OCCURRENCE OR SEVERITY OF CORONARY HEART DISEASE

Physical activity may: Increase	Decrease
Coronary collateral vascularization	Serum lipid levels
Myocardial efficiency	triglycerides
Efficiency of peripheral blood distribution and return	cholesterol
Fibrinolytic capability	Glucose intolerance
Red blood-cell mass and blood volume	Arterial blood pressure
Tolerance to stress	Neurohormonal influences
Prudent living habits	"Strain" associated with psychic "stress"
Joie de vivre	

of disease symptoms or diagnosis. While this sort of manipulation is quite difficult in a collaborative study of these proportions, the study appears valid, and the results seem meaningful despite inherent difficulties.

In summary, we see that in Morris and Crawford's data, patches, scars, infarcts, and occlusions are less frequent in those who are more active physically, but that there is slight difference in relation to atherosclerosis in the vessels themselves.

The findings from Spain and Bradess' CHD pathologic study in Westchester County are essentially the same as Morris and Crawford's as regards the degree of coronary atherosclerosis: no significant differences were found between subjects who had been physically active and those who were classified as sedentary.[22]

How Physical Activity May Have an Influence

The possible mechanisms by which physical activity may reduce the occurrence or severity of CHD are worthy of consideration. In general we regret that we have all too little information on these mechanisms (see accompanying table).

Increased coronary vascularization. Since hypoxia is the greatest known dilator of coronary vessels an increase in coronary vascularization is likely to be a direct response of "ischemic stress." Eckstein[23] compromised the myocardial blood supply of dogs by partially constricting the circumflex coronary arteries. Increased vascularization did not occur after mild constriction unless exercise was also performed. With moderate or severe constriction the amount of vascularization was again greater in exercised dogs than in the nonexercising controls.

Tepperman and Pearlman[24] found an increase in the size of the coronary tree of rats that swam 30 minutes twice daily but found no difference between exercised and nonexercised guinea pigs. They estimated the size of the coronary tree from the weight of a vinyl acetate cast of the tree. Using the same technique, Stevenson and his co-workers[25] found an increase in coronary vascularization per unit mass of the myocardium in rats that exercised by running or swimming. With both treadmill running and swimming, it appeared that moderate exercise with regard to frequency, intensity, and duration was more effective at increasing vascularization than more strenuous exercise. That heavy physical activity may result in larger coronary arteries in humans is suggested by the autopsy findings on the great distance runner, Clarence De Mar.[26] The recent report on this subject by Rose and his coworkers[27] is very intriguing but inconclusive.

We are unaware of any report on the systematic measurement of changes in coronary vascularization in live humans due to increased physical activity. Hellerstein *et al.*[28] reported that in a postinfarction patient who had pre- and posttraining coronary angiograms there was "clear evidence of an increase in collateral circulation following training." A second patient did not show this same favorable response even though the training program increased his physical working capacity. Kattus[29] has also reported a similar situation. Although most encouraging, these are but several isolated cases without controls to indicate what occurs under circumstances similar in every respect except for an increase in physical activity.

Myocardial function. Investigations into electrocardiographic, hemodynamic, and metabolic parameters influenced by physical training indicate that regular participation in programs of exercise endurance may reduce the frequency or severity of CHD by enhancing cardiovascular function, especially myocardial efficiency.[30] If this is the case, then the atherosclerotic process itself does not necessarily have to be altered in order for increased habitual physical activity to be of benefit.

A number of investigators have reported decreased electrocardiographic abnormalities, especially ischemic RS-T segment displacement, in subjects whose test workload following a physical training program was the same or heavier than their workload prior to training.[31-33] These changes might be due to improved myocardial efficiency, changes in peripheral distribution of blood and its return, decreased pressure or flow requirements as well as to a possible increase in coronary vascularization. Keys *et al.*[34] in a recent study of men 40 to 59 years old in 12 locations in Europe and the United States reported an inverse relation between the frequency of ECG measurement related to myocardial dysfunction and the intensity of their occupational physical activity.

A direct measurement of the requirement for myocardial oxygen or for its expenditure is not readily obtainable. Indirect measures, however, indicate that increased physical activity may enhance myocardial or total cardiovascular efficiency during rest and exercise. Changes that occur with training which may result in a more advantageous use of coronary flow include 1) bradycardia during rest and submaximal exercise, 2) an increase in resting and exercise stroke volume, 3) an increase in maximum cardiac output, 4) a longer diastolic period available for coronary perfusion, 5) a reduction in heart-chamber size at the same work load, 6) myocardial hypertrophy, 7) a decrease in systemic arterial pressure, and 8) redistribution of blood flow to more active muscles. The significance of these changes relative to the consequence of the atherosclerotic-thrombotic process of disease is that the lower the oxygen requirement of the heart (during rest or any level of exercise) the lower the coronary flow rate can be and still be adequate.

Only very preliminary data are available on the influence of increased habitual physical activity on changes in metabolic or cellular membrane phenomena which may influence myocardial efficiency. The intriguing hypothesis proposed by Raab and colleagues that physical inactivity causes deterioration of vagal and sympathoinhibitory counterregulation against oxygen-wasting adrenergic preponderance warrants further investigation.[35]

Serum lipids. The influence of increased physical activity on various serum lipids, especially serum cholesterol, has not been definitively established. In certain studies where exercise appeared to have a lowering effect on serum cholesterol, little or no information was available on the dietary habits of the subjects; a number of subjects had significant reductions in body weight.[36, 37] Recently Berkson *et al.*[38] and Mann *et al.*[39] reported reductions in serum cholesterol in middle-aged men on a program of exercise even though no significant reduction in body weight was observed.

In other reasonably well-controlled studies, such as that reported by Goode *et al.*,[40] where increased physical activity was not accompanied by a decrease in body weight, there was no reduction in cholesterol level. Naughton and McCoy[41] reported similar reductions in serum-cholesterol levels in a group of 24 healthy and cardiac subjects who trained for eight months with no loss in body weight (298.3 to 226.4 mg./100 ml.), and in a group of sedentary control subjects (223.7 to 184.5 mg./100 ml.). They attributed these reductions not to increased physical activity, dietary changes, or seasonal variation, but to an increased familiarity of the subjects with the testing procedures.

Except for the recent report of Mann *et al.*[39] the results of studies on the influence of increased physical activity on serum triglycerides have been quite favorable and consistent. It appears that exercise can reduce both the fasting and the increased serum triglyceride level that generally accompanies postprandial lipemia.[42, 43] Shane[44] found a significant inverse relation between physical condition and postprandial serum triglyceride levels. Similar results were observed by Hoffman and his coworkers[45] on a sample of senior air-force officers.

The reduction in fasting triglyceride levels by exercise, even if the exercise must be performed every two or three days to maintain a lower level, is very encouraging since hyperlipemia has been associated with accelerated blood clotting, increased viscosity, and the adhesiveness and aggregation of red blood cells.[46, 47] Also, impaired myocardial oxygen extraction, decreased coronary blood flow, decreased capacity of physical performance, and anginal attacks have been reported in man during alimentary lipemia.[48, 49]

Blood coagulation and fibrinolysis. Physical activity of light or moderate intensity (Master's step test,[50] a 10 to 20 minute walk at 3 mph.,[51] or an 8-minute walk at 3.5 mph. and 5° grade[52]) significantly increases fibrinolytic activity at least temporarily. Data on more strenuous activity, especially competitive games, are less consistent; some investigators observed increases in fibrinolytic activity or related parameters,[51] while others have observed an opposite effect.[53] Some of this discrepancy may be due to the means by which the blood-clotting mechanism is evaluated and the type of exercise performed. There is some suggestion that an increase in habitual physical activity may have a favorable chronic effect on blood clotting of fibrinolytic mechanisms.[54]

Blood pressure. Little is known regarding the chronic effects of physical activity on basal or resting blood-pressure levels. Miall and Oldham[55] and Morris and Crawford[56] have reported that hypertension occurs less frequently and at later ages in more active persons. Various investigators, including Naughton and his associates,[57] Berkson,[38] and Mann,[39] have reported a reduction in systolic and diastolic blood pressure at rest and at a given work load after participation in an endurance type of physical activity. More well-controlled intervention studies of the long-term effects of increased habitual physical activity on resting or "operational" blood pressure are needed.

Obesity. Physical activity, though generally considered to be less efficient than strict dieting for the control of obesity, may be for many individuals a more attractive and successful procedure for reduction to, and maintenance of, desirable body weight and composition. Increased physical activity of adequate frequency, duration, and intensity will allow an individual to follow a less restricted diet and thus avoid the dissatisfaction and anxiety associated with severe dieting. When attempting to use increased physical activity as a means of helping to control body weight, it is important to keep in mind that the benefits of exercise for this purpose are cumulative and that appetite does not automatically increase with an increase in activity.

Psychic reactivity. If mental conflicts or "stresses" produce a "physiological strain" that influences the manifestations of CHD, it is possible but still unproved that physical activity may modify this reaction favorably. It seems important to determine whether the feeling of increased well-being and enhanced personal image which many individuals find accompanies physical conditioning make them more tolerant of, or less vulnerable to "psychic stress." It would also be worthwhile to know if regular physical activity influences other health-related habits such as smoking, sleeping, or desire for stimulating beverages.

Additional considerations. Additional factors that may alter the course of CHD and that may be influenced by an increase in habitual physical activity are controversial increases in glucose tolerance,[58, 59] red blood-cell mass and blood volume.[60, 61] Also, the possible reduction of functional circulatory insufficiency in "asthenic" individuals by systematic exercise, as pointed out by Holmgren,[62] may not reduce cardiovascular morbidity but may increase the work capacity and productivity of a sizable segment of our sedentary population.

With respect to the reduction of cardiovascular disability, the recent work by Skinner and Strandess[63] on exercise and intermittent claudication is most encouraging. Patients with inadequate blood flow to the lower leg and ankle due to moderate arteriosclerosis obliterans performed a program that consisted of intermittent walking on a treadmill. Substantial increases occurred in the time at which claudication pain began, in maximal walking time, and the resting and postexercise systolic ankle pressure. These changes were attributed to an increase in collateral vascularization in the obstructed leg. Similar findings have been reported by Larson and Lassen.[64]

Summary

1) On the basis of numerous studies, individuals presumed to be more active physically have less coronary heart disease. This applies to both occupational and nonoccupational activity.

2) Associated though not as yet closely-related selection factors of a personal nature, as well as those determined by skill and ability, are the chief considerations with which we must currently contend in our attempts to delineate "causal" relations.

3) Apparently, endurance-type exercise is more valuable than strength-type or isometric exercise, although this judgment is not based on adequate measurement techniques or sizable studies.

4) It appears that for exercise to be of benefit it must be continuous throughout one's life, i.e., that one cannot "store up" the benefits of earlier athletic performance, such as that done in college.

5) The influence of physical activity on infarction, scars, and fibrous patches appears to be more striking than its influence on the atherosclerotic process as such.

6) Again, the benefits of activity may result in part from the stimulus it provides toward more prudent behavior relative to smoking, weight control, coffee consumption and, perhaps, even the manner in which we are able to handle the stress and strain of life.

7) Last, we must examine approaches regarding how to motivate people to become more physically active.

Robert Frost has said: "The world is full of willing people; a few who are willing to work and many who are willing to let them." This may apply to the attitudes of people toward becoming physically more active.

Perhaps uniquely relevant to the proposal to include increased physical activity as helpful in the prevention of CHD is the relatively prompt "positive feedback" of enhanced feelings of well-being that are appreciated by many as they become more active.

An assessment of the data leaves us wanting far more information, but I believe we can consider it highly prudent to include programs of inceased habitual activity in our multifactorial approach to the prevention of coronary heart disease.

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