Jere H. Mitchell

STATIC (ISOMETRIC) EXERCISE AND THE HEART:
PHYSIOLOGICAL AND CLINICAL CONSIDERATIONS

MEDICAL GRAND ROUNDS

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Tom and Lula Gooch Auditorium
University of Texas Health Science Center at Dallas

July 31, 1975

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I. INTRODUCTION

1. Lind, A.R., McNicol, G.W. and Donald, K.W.: Circulatory adjustments to sustained (static) muscular activity. In Physical Activity in Health and Disease. Ed. Erang and Anderson - The Williams & Wilkins Co. Proceedings of Beitostolen Symposium, 1966, pp 38-63.

2. Nutter, D.O., Schlant, R. C. and Hurst, J.W.: Isometric exercise and the cardiovascular system. Modern Concepts of Cardiovascular Disease, 41:11, 1972.

3. Mitchell, J.H. and Wildenthal, K.: Static (isometric) exercise and the heart: physiological and clinical considerations. Annual Rev. Med. 25:369, 1974.

4. Moran, L.: In Winston Churchill: The Struggle for Survival, 1940-65. Constable, London, 1966.

During the performance of muscular exercise, the heart and the vascular system undergo important adaptive changes. The exact nature of these changes depends upon the specific type of exertion undertaken. Broadly speaking, there are two main types of activity. Exercise in which skeletal muscle contraction causes principally a change in tension with little change in length is termed static or isometric, and that in which the contraction causes principally a change in length with little change in tension is termed dynamic or isotonic. Most muscular exercise is neither purely static nor purely dynamic. Exercises that are predominantly static include lifting or pushing heavy weights and contracting muscles against fixed objects, and those predominantly dynamic include running, swimming, bicycling, and rhythmic calistenics.

Historically, there has been extensive interest in and investigation of the cardiovascular effects of exercise in health and disease, but the form of exercise that has been studied almost exclusively has been dynamic exercise. It has only recently been recognized that static exercise places an important stress on the normal and especially the diseased heart. One important example of this was reported by Lord Moran in his book on Winston Churchill.

Washington, December 27, 1941....

'I am glad you have come,' the PM (Churchill) began. He was in bed and looked worried.
'It was hot last night and I got up to open the window. It was very stiff. I had to use considerable force and I noticed all at once that I was short of breath. I had a dull pain over my heart. It went down my left arm. It didn't last very long but it has never happened before. What is it? Is my heart all right? I thought of sending for you but it passed off...

...I (Moran) had no doubt that whether the electro-cardiograph showed evidence of a coronary thrombosis or not, his symptoms were those of coronary insufficiency.

The purpose of this Grand Rounds is to describe what is known of the acute and chronic physiological effects of static exercise on the heart and circulation. In addition a discussion of the clinical use of isometric exercise in the diagnosis of cardiac disease and the special consequences of this type of muscular activity in patients with cardiovascular problems will be presented.

II. CARDIOVASCULAR EFFECTS OF STATIC EXERCISE

A. Acute Effects of Static Exercise

1. Human Studies

5. Lindhard, J.: Untersuchungen uber statische Muskelarbeit. Skandin. Archiv. 40:145, 1920.

6. Alam, M. and Smirk, F.H.: Observations in man upon a blood pressure raising reflex arising from the voluntary muscles. J. Physiol. 89:372, 1937.

7. Alam, M. and Smirk, F.H.: Observations in man on a pulse-accelerating reflex from the voluntary muscles of the legs. J. Physiol. 92:167, 1938.

8. Asmussen, E. and Hansen, E.: Über den einflub statischer Muskelarbeit auf atmung and kreislauf. Der Redaktion am 22:283, 1937.

9. Tuttle, W. W. and Horvath, S.M.: Comparison of effects of static and dynamic work on blood pressure and heart rate. J. Appl. Physiol. 10:294, 1957.

10. Lind, A.R., Taylor, S.H., Humphreys, P.W., Kennelly, B.M. and Donald, K.W.: The circulatory effects of sustained voluntary muscle contraction. Clin. Sci. 27:229, 1964.

11. Staunton, H.P., Taylor, S.H. and Donald, K.W.: The effects of vascular occlusion on the pressor response to static muscular work. Clin. Sci. 27:283, 1964.

12. Lind, A.R. and McNichol, G.W.: Local and central circulatory responses to sustained contractions and the effect of free or restricted arterial inflow on post-exercise hyperanemia. J. Physiol. 192:575, 1967.

13. Lind. A.R. and McNichol, G.W.: Circulatory responses to sustained hand-grip contractions performed during other exercise, both rhythmic and static. J. Physiol. 194:595, 1967.

14. Donald, K.W., Lind, A.R., McNicol, G.W., Humphreys, P.W., Taylor, S.H. and Staunton, H.P.: Cardiovascualr responses to sustained (static) contractions. Cir. Res. 20 and 21 suppl 1:15, 1967.

15. Lind, A.R., McNichol, G.W., Bruce, R.A., Macdonald, H.R. and Donald, K.W.: The cardiovascular responses to sustained contractions of a patient with unilateral syringomyelia. Clin. Sci. 35:45, 1968.

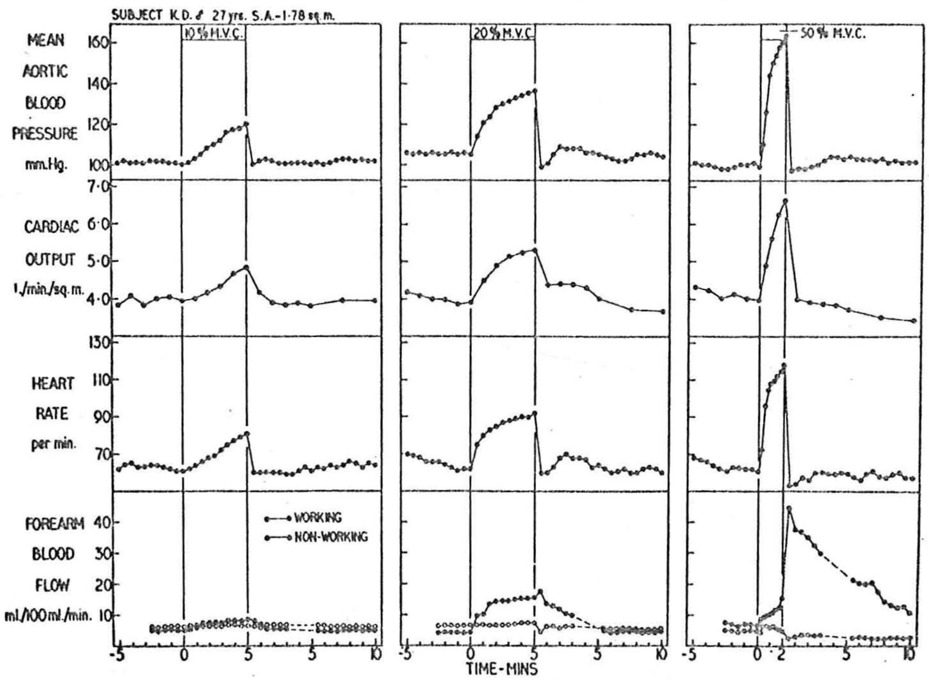
16. Freyschuss, U.: Cardiovascular adjustment to somatomotor activation. The elicidation of increments in heart rate, aortic pressure and venomotor tone with the initiation of muscle contraction. Acta Physiol. Scand., Suppl. 342:1, 1970.

During the first half of this century, occasional studies were made of partially static exercise, but only a few dealt systemically with the topic. It was generally assumed that the most important special aspect of static exertion was that blood flow to the muscle was inadequate due to maximal occlusion of the artery of the contracting muscle fibers. However, it was noted that mild tachycardia and dramatic increases in arterial pressure invariably accomplished this exertion.

It was not until the 1960's that an extensive and comprehensive investigation of the special characteristics of isometric exercise was undertaken. The studies of Lind, Donald and colleagues and those of Freyschuss remain the primary sources of basic information on the physiology of cardiovascular responses to isometric exercise. In the studies of Lind, graded degrees of handgrip contractions were used. An example of this type study by Lind is shown in Figure 1.

Figure 1.

HAEMODYNAMIC RESPONSE TO HAND-GRIP

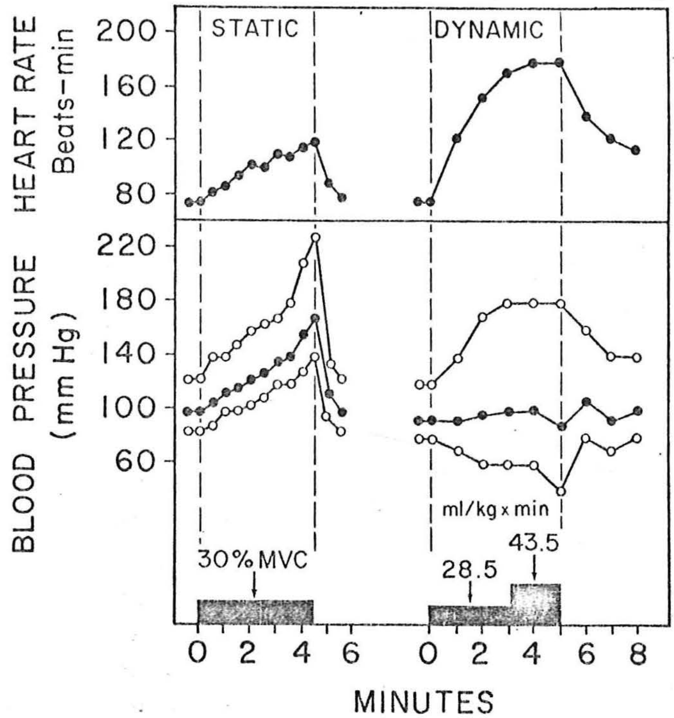


The cardiovascular responses in a normal subject during and after sustained handgrip contraction at 10, 20 and 50% of maximal voluntary contraction (MVC) are shown. A small increase in mean arterial blood pressure, cardiac output and heart rate occured at 10% MVC. At 20% MVC the changes were greater and at 50% MVC mean arterial blood pressure increased about 60 to 70 mm Hg and heart rate increased about 30 to 40 beats/minute.

It is of special interest that neither the absolute tension development nor the size of the muscle group is the determining factor; rather, the important element seems to be the percentage of maximal contraction by the particular muscle group involved. Thus, blood pressure rises to a similar extent with 20% of maximal handgrip, 20% of maximal contraction by thigh muscles, or 20% of maximal adduction of individual fingers, despite the manyfold differences in absolute tension developed and in the energy requirements of the respective efforts.

Static contractions of the forearm muscle of one arm causes a marked increase in mean arterial blood pressure with a relatively small increase in heart rate and cardiac output as compared to dynamic exercise. A comparison of the heart rate and arterial blood pressure response to 30% MVC and to dynamic exercise on a treadmill is shown in Figure 2.

Figure 2



This study clearly shows the marked rise of blood pressure with an increase in heart rate during static exercise which contrasts with the large rise in heart rate with little change in mean arterial blood pressure during dynamic exercise. Also the cardiac output only increases to about 6 liter/min with static exercise and may increase to 20 to 25 liter/min with dynamic exercise. Thus, static exercise may be thought of as causing primarily a pressure load on the heart, whereas dynamic exercise produces primarily a volume load on the heart.

17. Mullins, C.B., Leshin, F.J., Mierzwiak, D.S., Matthews, O.A., and Blomqvist, G.: Sustained forearm contraction (hand-grip) as a stress test for evaluation of left ventricular function. Clin. Res. 18:322, 1970 (Abstr.).

18. Helfant, R.H., deVilla, M.A., and Meister, S.G.: Effect of sustained isometric handgrip exercise on left ventricular performance. Circul. 44:982, 1971.

19. Kivowitz, C., Parmley, W.W., Donoso, R., Marcus, H., Ganz, W., and Swan, H.J.C.: Effects of isometric exercise on cardiac performance. The grip test. Circul. 44:994, 1971.

20. Krayenbuehl, H.P., Futishauser, W., Schoenbeck, M. and Amende, I.: Evaluation of left ventricular function from isovolumic pressure measurements during isometric exercise. Am. J. Cardio. 29:323, 1972.

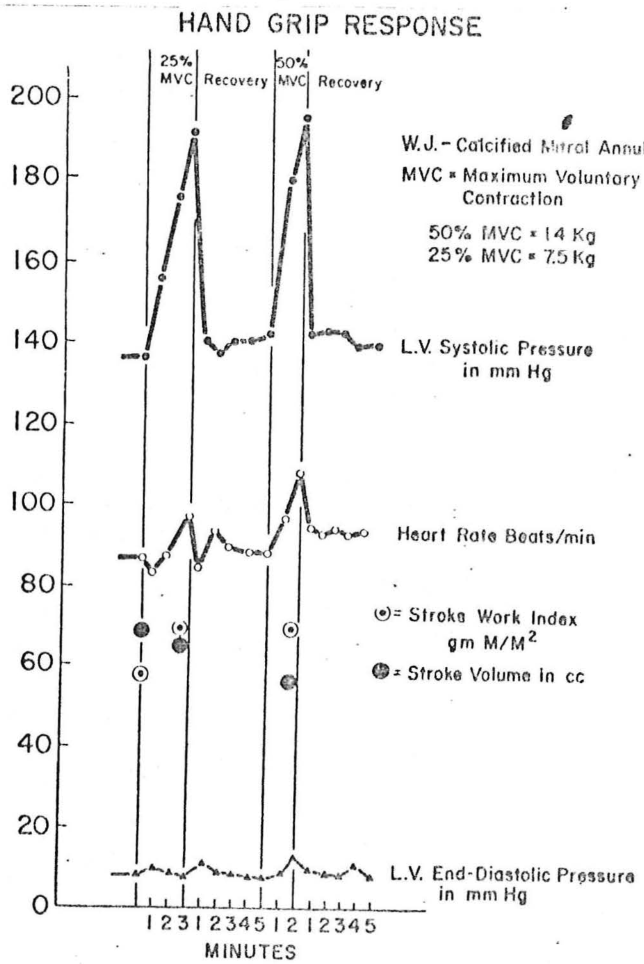
21. Amende, I., Krayenbuehl, H.P., Rutishauser, W., and Wirz, P.: Left ventricular dynamics during handgrip. Brit. H. Jour. 34:688, 1972.

22. Mullins, C.B., and Blomqvist, G.: Isometric exercise and the cardiac patient. Tex. Med. 69:1, 1973.

23. Fisher, M.L., Nutter, D.O., Jacobs, W. and Schlant, R.C.: Haemodynamic responses to isometric exercise (handgrip) in patients with heart disease. Brit. H. Jour. 35;422, 1973.

During the past five years evaluation of isometric exercise responses has been performed in many laboratories during left heart catheterization, and the normal response to varying levels of exertion has been defined. As a rule, the marked increase in after-load that results from the static exertion is accompanied by an increase in left ventricular contractile force, however measured. There is no change or only a small rise (5 mm Hg) in left ventricular end diastolic pressure, implying that the Starling mechanism is not required in a major way to meet the imposed stress. The extent of rise end diastolic pressure varies with the pressure load, as would be expected. Mullins & Blomqvist have described typical responses in a patient with relatively normal left ventricular function and these are shown in Figure 3.

Figure 3



At both 25% and 50% of maximal voluntary contraction in a patient with a calcified mitral annulus, there was a marked increase in left ventricular systolic pressure and a moderate increase in heart rate. Stroke work index increased significantly while left ventricular end-diastolic pressure remained constant at 25% of maximal voluntary contraction and only increased slightly at 50%.

24. Grossman, W., McLaurin, L.P., Saltz, S.B., Paraskos, J.A., Dalen, J.E., and Dexter, L.: Changes in the inotropic state of the left ventricle during isometric exercise. Br. Heart J. 35:697, 1973.

25. Quinones, M.A., Gaasch, W.H., Waisser, E., Thiel, H.G., and Alexander, J.K.: An analysis of the left ventricular response to isometric exercise. Amer. Heart J. 88:29, 1974.

26. Martin, C.E., Shaver, J.A., Leon, D.F., Thompson, M.D., Reddy, P.S. and Leonard, J.J.: Autonomic mechanisms in hemodynamic responses to isometric exercise. J. Clin. Invest. 54:104, 1974.

27. Kozlowski, S., Brzezinska, Z., Nazar, K., Kowalski, W. and Franczyk, M.: Plasma catecholamines during sustained isometric exercise. Clin. Sci. Molecular Med. 45:723, 1973.

In the normal left ventricle there is a marked increase in contractility during isometric exercise. This has been shown by analysis of ventricular function curves and isovolumic indicies of myocardial contractility. Further, studies of plasma catecholamines during sustained isometric exertion suggest that the hemodynamic responses are due to a powerful activation of the adrenergic nervous system.

2. Animal Studies

28. Coote, J.H., Hilton, S.M. and Pèrez-Gonzàles, J.F.: The reflex nature of the pressor response to muscular exercise. J. Physiol. (London) 215:789, 1971.

29. McCloskey, D.I. and Mitchell, J.H.: Reflex cardiovascular and respiratory responses originating in exercising muscle. J. Physiol. (London) 224:173, 1972.

30. Fisher, M.L. and Nutter, D.O.: Cardiovascular reflex adjustments to static muscular contractions in the canine hindlimb. Amer. J. Physiol. 226:648, 1974.

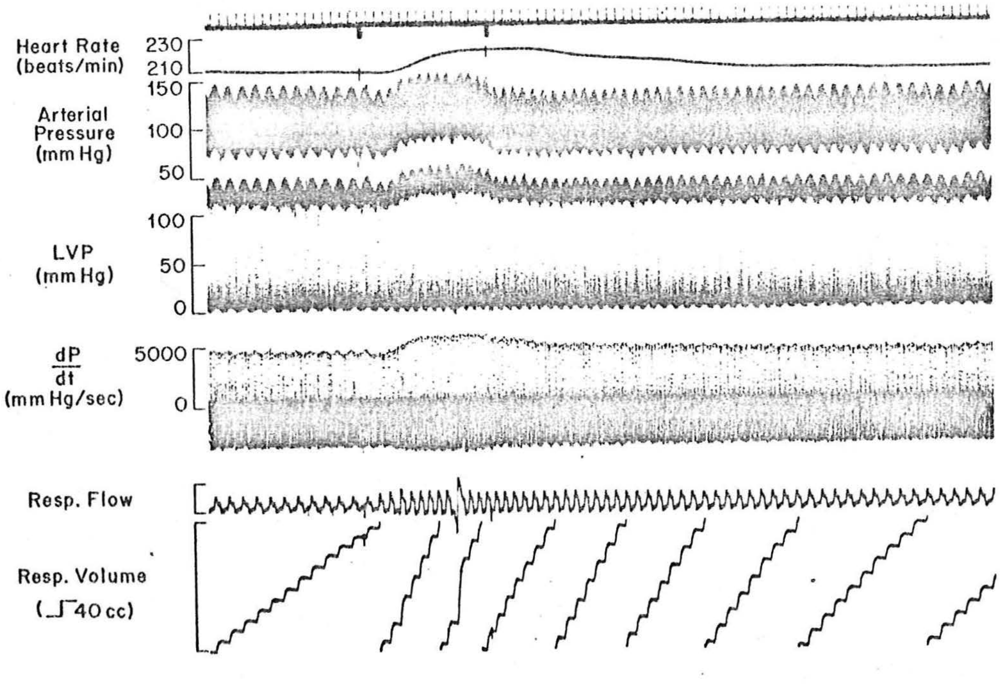
31. Reardon, W.C., McCloskey, D.I. and Mitchell, J.H.: Cardiovascular responses during induced isometric exercise. Clin. Res. 22:12, 1974 (Abstr.).

32. Crayton, S., Aug-Ding, R., Fixler, D. and Mitchell, J.H.: Distribution of Cardiac output during static muscular contractions of the canine hind limb. Fed. Proc. 34:421, 1975 (Abstr).

33. Diepstra, G, Gonyea, W. and Mitchell, J. H.: Preliminary observations.

The cardiovascular effects of static exercise have been further examined in experiments on anesthetized cats and dogs. A study of isometric exercise in cats induced by stimulating spinal ventral roots was carried out by Reardon *et.al* and is shown in Figure 4.

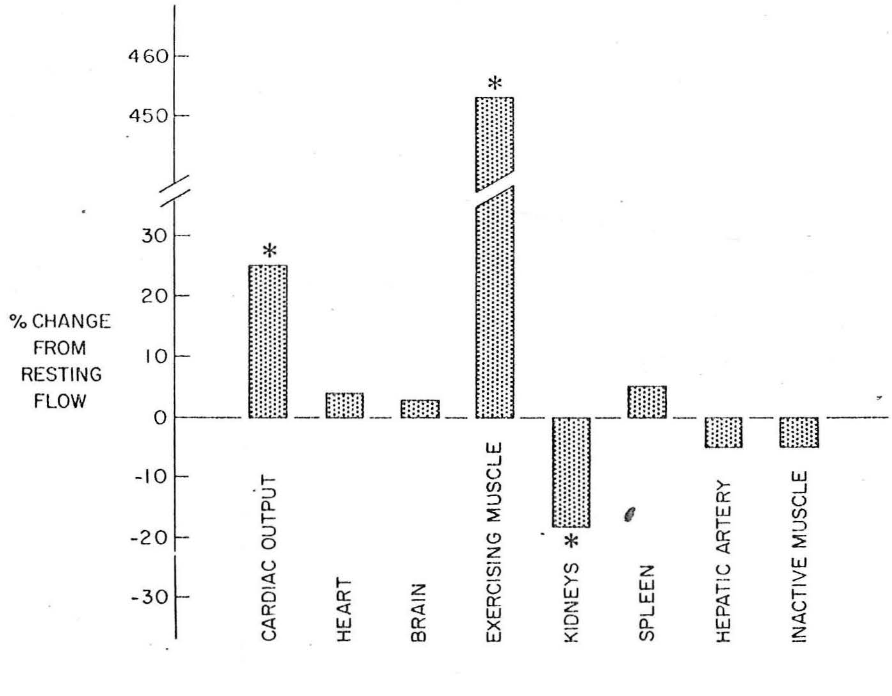
Figure 4



During induced isometric exercise there was an increase in heart rate, arterial blood pressure, left ventricular systolic pressure and the maximal rate of left ventricular pressure rise. Further analyses demonstrated that there was a marked increase in the contractile state of the left ventricle which disappeared after β-adrenergic receptor blockade with propranolol.

It has also been shown in studies of induced isometric exercise in dogs that there is an increase in cardiac output which is also abolished by β-adrenergic receptor blockade with propranolol. Further, Crayton has determined the distribution of cardiac output during induced isometric exercise by radioactive microspheres and this is shown in Figure 5.

Figure 5



During induced isometric exercise there was a 26% increase in cardiac output. The greatest change in flow was to the isometrically exercising hind limb which increased by 453%. Renal blood flow decreased by 18%. Flow to the brain, spleen, liver (via hepatic artery) and inactive muscle remained near control values. Of interest is that flow to the heart did not increase significantly during induced isometric exercise. Since isometric exercise increases heart rate, arterial blood pressure, and contractility of the left ventricle, it would appear that myocardial oxygen demands would be significantly increased.

The failure of coronary blood flow to increase under these circumstances suggest that isometric exercise causes selective coronary vasoconstriction. Such a possibility is being further studied in both the anesthetized dog during induced isometric exercise and in some preliminary studies on awake cats performing voluntary isometric exercise.

B. Acute Effects of Combined Static and Dynamic Exercise

13. *Loc. Cit.*

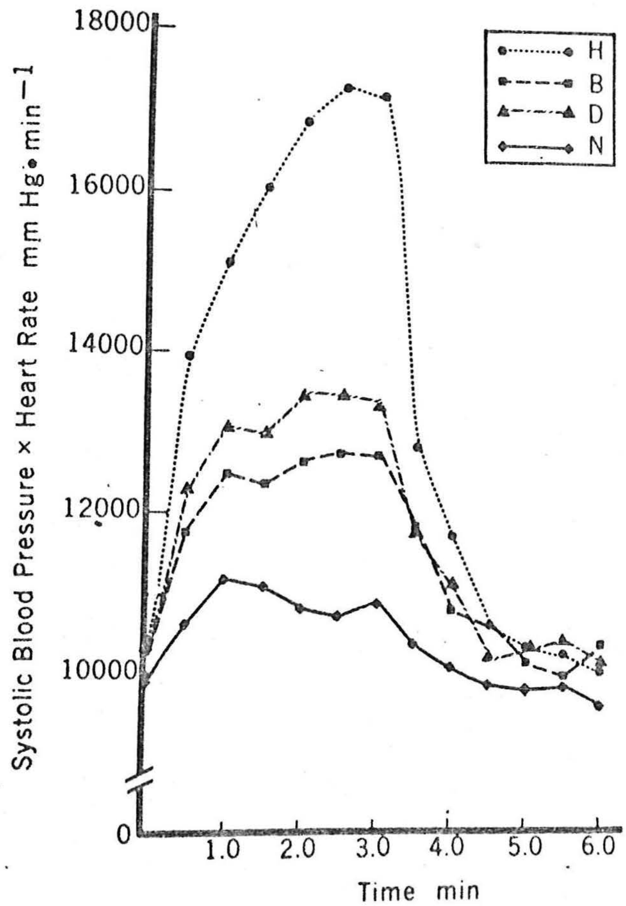
34. Lind, A.R., McNicol, G.W.: Cardiovascular responses to holding and carrying weights by hand and by shoulder harness. J. Appl. Physiol. 25:261, 1968.

35. Jackson, D. H., Reeves, T. J., Sheffield, L.T. and Burdeshaw, J.: Isometric effects on treadmill exercise response in healthy young men. Amer. J. Cardiol. 31:344, 1973.

36. Nelson, R.R., Gobel, F.L., Jorgensen, C.R., Wang, K., Wang, Y. and Taylor, H.L.: Hemodynamic prediction of myocardial oxygen consumption during static and dynamic exercise. Circ. 50: 1179, 1974.

The cardiovascular changes induced by static exercise persist, undiminished, during dynamic exercise. This has potential importance in terms of myocardial oxygen demands. It has been shown that the double product (systolic blood pressure X heart rate) is a good index for the prediction of myocardial oxygen consumption during static and dynamic exercise. The fact that this index is higher during combined static and dynamic exercise is shown in Figure 5.

Figure 6



A normal subject walked on a treadmill at 1.7 mph and 0% grade. When not carrying a load (N) there was a small increase in the double product indicating little increase in myocardial oxygen demands. When he carried a 40 lb weight on his back (B) or a 20 lb weight in each hand (D), there was a further increase in myocardial oxygen demands. However, when the subject carried a 40 lb weight in one hand (H) there was a marked increase in the double product. Thus the myocardial oxygen demands for a given combined static and dynamic exercise load can be regulated by the load distribution. The importance of this finding will be discussed later in the section on static exercise in patients with coronary heart disease.

C. Chronic Effects of Static Exercise

37. Muller, E.A.: Physiological methods of increasing human physical work capacity. Ergonomics Research Society. The Society's Lecture, 1965, pp. 410-424.

38. Saltin, B. and Åstrand, P.-O.: Maximal oxygen uptake in athletes. J. Appl. Physiol. 33:353, 1967.

39. Keul, J.: The relationship between circulation and metabolism during exercise. Medicine and Science in Sports. 5:209, 1973.

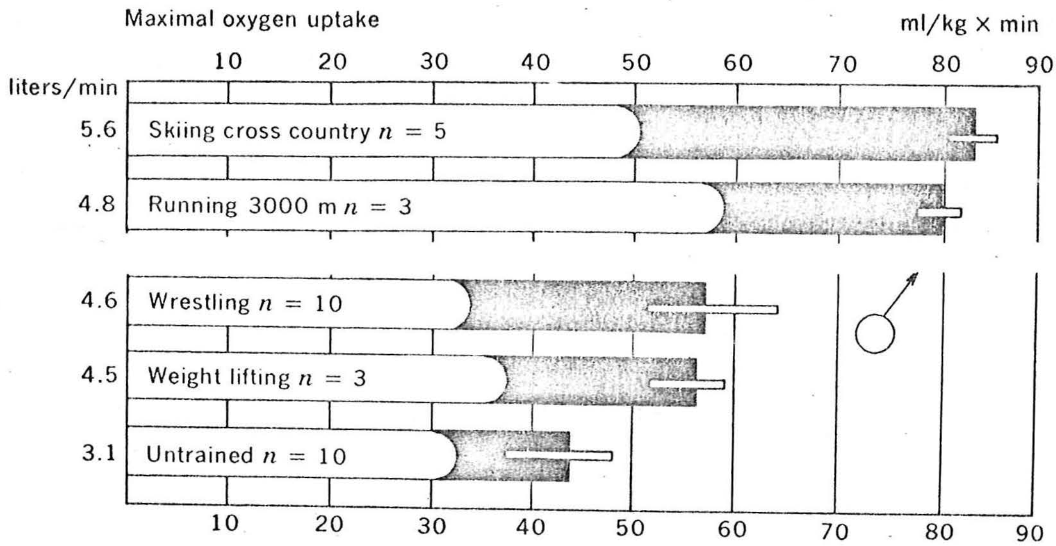
40. Lind, A. R.: Cardiovascular responses to static exercise. (Isometrics, anyone?). Circulation 41:173, 1970.

41. Reindell, H., Klepzig, H., Steim, H., Musshoff, K., Roskamm, H., and Schildge, E.: Herz, Kreislaufkrankheiten und Sport. Barth-Verlag-München, 1970.

In recent years there has been much popular interest in isometric exercise as a quick and easy way for busy city dwellers to achieve physical fitness. However, even intense and prolonged programs of isometric training lead to little or no significant increase in maximal oxygen uptake or cardiac reserve.

The maximal oxygen uptake of champion Swedish athletes in various sports has been studied by Saltin and Åstrand and these are shown in Figure 7.

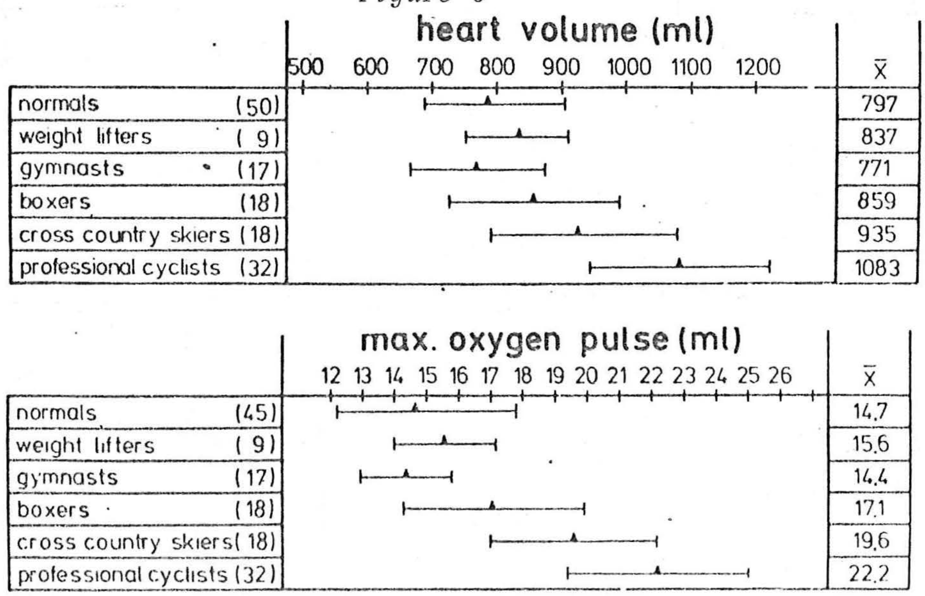
Figure 7



It is seen that maximal oxygen uptakes are increased in athletes in sports requiring high intensity dynamic training such as cross country skiing and distance running and are just above untrained subjects in athletes competing in sports requiring predominantly static training such as wrestling and weight lifting. In fact champion table tennis players have higher maximal oxygen uptakes than do weight-lifters.

Keul has also shown that athletes participating in dynamic exercise training have larger hearts and larger maximal oxygen pulses than do weight lifters or normal subjects. This is shown in Figure 8.

Figure 8



The total heart volumes of normal subjects and weight lifters are smaller than cross country skiers or professional cyclists. Also the maximal amount of oxygen delivered each beat (maximal oxygen pulse) is higher in cross country skiers and professional cyclists than in weight lifters or normal subjects.

It is possible, however, that champion athletes choose their events because of genetic predisposition. However, a study by Keul of idential twins has shown that this is probably not the case. One of the twins trained for several years in weight lifting and the other in endurance running. The weight lifter was 16 kg heavier than the runner but both his maximal oxygen uptake (1.8 l/min) and heart volume (560 ml) were smaller than the runner whose maximal oxygen uptake was 2.5 l/min and heart volume was 710 ml.

III. DIAGNOSTIC USE OF STATIC EXERCISE IN CARDIOVASCULAR DISEASE

A. Evaluation of Valve Lesions

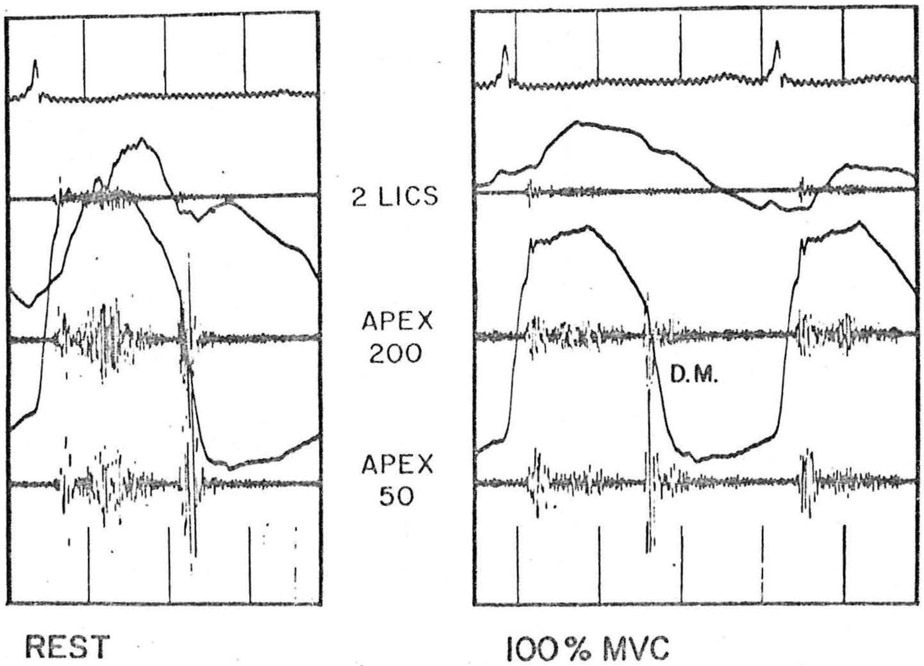
42. McCraw, D.B., Siegel, W., Stonecipher, H.K., Nutter, D.O., Schlant, R.C., and Hurst, J.W.: Response of heart murmur intensity to isometric (handgrip) exercise. Brit. Heart J. 34:605, 1972.

43. Ramakrishna, N.C.: Sustained isometric handgrip. Ohio State Med. J. 69:113, 1973.

44. Cassidy, J., Aronow, W.S., and Prakash, R.: The effect of isometric exercise on the systolic murmur of patients with idiopathic hypertrophic subaortic stenosis. Chest 67;395, 1975.

Isometric exercise has been used to characterize and differentiate the origin of murmur from several types of valve lesions. The effect of this manuever on the murmurs from aortic valve disease is shown in Figure 9.

Figure 9



During rest there is a prominent systolic ejection murmur and a minimal diastolic murmur. Using 100% maximal voluntary contraction (MVC) the intensity the systolic ejection murmur decreases and that of the diastolic murmur increases.

The effect of isometric exercise on murmurs from the mitral valve are shown in Figures 10 and 11.

Figure 10

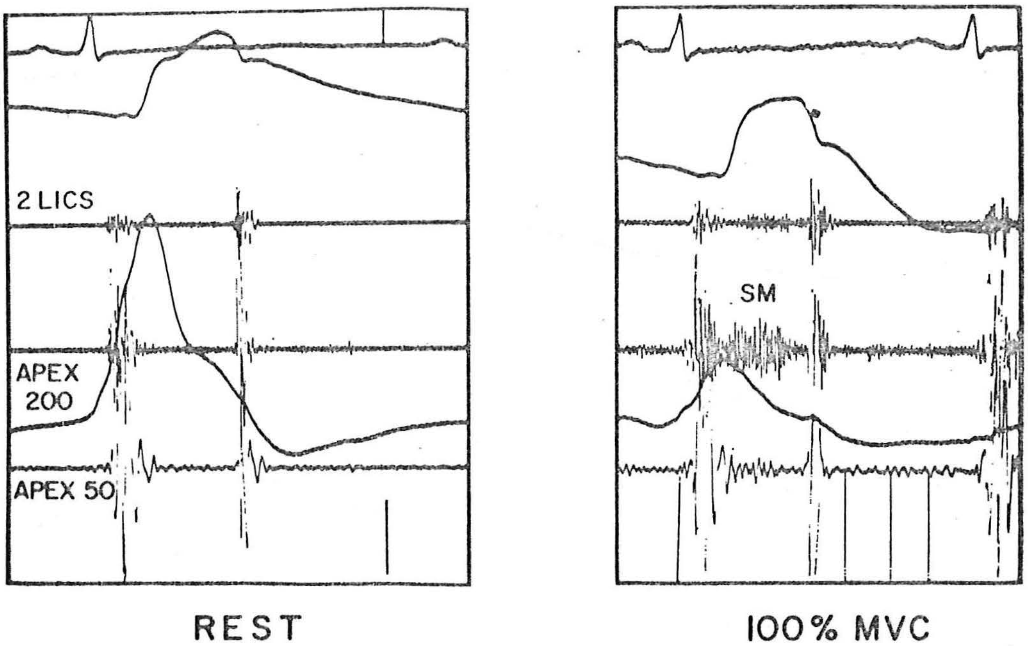
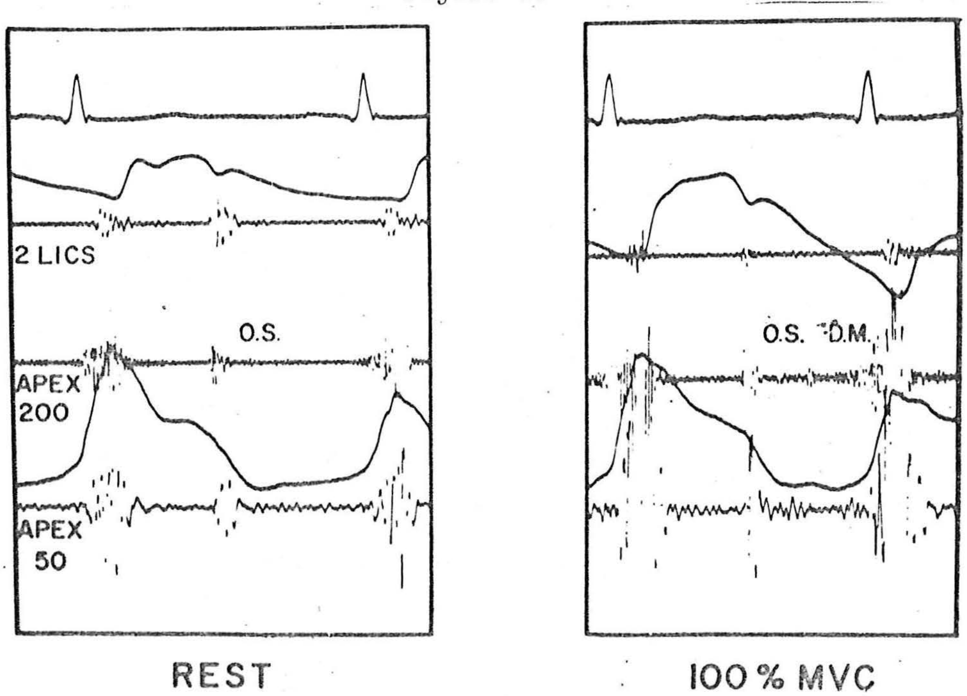


Figure 11



In Figure 10 the soft holosystolic murmur of mitral regurgitation is markedly accentuated by isometric handgrip. In Figure 11 from a recording of a patient with mitral stenosis, isometric handgrip increased the intensity of the mitral diastolic murmur.

Thus isometric handgrip is useful in differentiating the systolic murmur of aortic and mitral origin. The systolic murmur of aortic origin becomes less intense and that of mitral origin becomes more intense. Since handgrip increases the intensity of the diastolic murmur of aortic regurgitation it is useful in distinguishing this lesion from pulmonic regurgitation in which the murmur is not altered by handgrip. Handgrip may intensify an inaduible murmur of mitral stenosis. Also the murmur of idiopathic hypertrophic subacute stenosis is decreased in intensity during static exercise.

B. Evaluation of Coronary Heart Disease

1. Estimation of the adequacy of myocardial blood flow

45. Jackson, D. H.: Isometric (dynamometer) stress testing in coronary heart disease. Alabama J. Med. Sci., 7:310, 1970.

46. Siegel, W., Gilbert, C.A., Nutter, C.O., Schlant, R.C. and Hurst, J.W.: Use of isometric handgrip for the indirect assessment of left ventricular function in patients with coronary atherosclerotic heart disease. Am. J. Cardiol. 30:48, 1972.

47. Helfant, R. H., Banka, V.S., DeVilla, M.A., Pine, R., Kakde, V. and Meister, S.G.: Use of bicycle ergometory and sustained handgrip exercise in the diagnosis of presence and extent of coronary heart disease. Brit. Heart J. 35:1321, 1973.

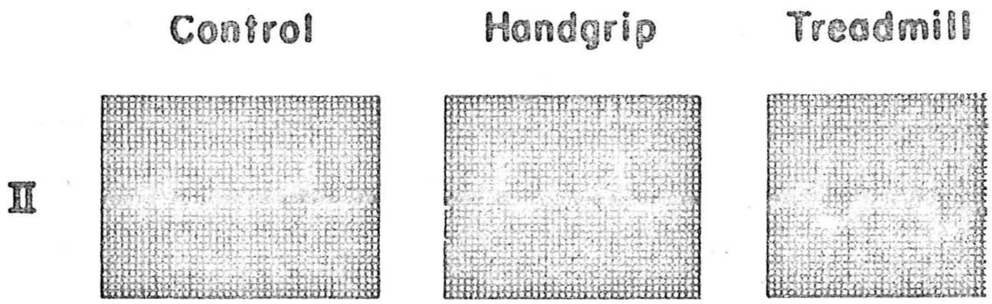
48. Haissly, J-C., Messin, R., Degre, S., Vandermoten, P., Demaret, B. and Denolin, H.: Comparative responses to isometric (static) and dynamic exercise tests in coronary disease. Amer. J. Cardiol. 33:791, 1974.

49. Kerber, R.E., Miller, R.A., and Majjar, S.M.: Myocardiac ischemic effects of isometric, dynamic and combined exercise in coronary artery disease. Chest 67:388, 1975.

50. Lowe, D.K., Rothbaum, D.A., McHenry, P.L., Corya, B.C. and Knoebel, S.B.: Myocardial blood flow response to isometric (handgrip) and treadmill exercise in coronary artery disease. Circul. 51:126, 1975.

It has been suggested that isometric exercise may have a useful role in evaluating the adequacy of myocardial blood flow in patients with coronary heart disease. However, this has not proved to be the case in most reported studies. It appears that dynamic exercise testing with a bicycle ergometer or treadmill is much more likely to produce angina pectoris or ST segment changes than is static exercise testing. Th effects of both handgrip and treadmill testing on Lead II of the electrocardiogram of a 55 year old man with severe three vessel coronary disease is shown in Figure 12.

Figure 12



The ischemic ST depression occurs during both tests, but is more severe with the treadmill test.

Several studies have suggested that static exercise stress testing is a less sensitive method for producing ischemic changes than dynamic exercise stress testing. This is probably due to less myocardial oxygen demand and higher aortic diastolic pressure (coronary perfusion) during static as compared to dynamic exercise.

In view of our previously discussed findings in animals, it would be of interest to determine if coronary blood flow is the same for a given double product (myocardial oxygen demand) produced by static and by dynamic exercise.

2. Estimation of the Occurrence of Cardiac Arrythmias

46. *Loc. Cit.*

47. *Loc. Cit.*

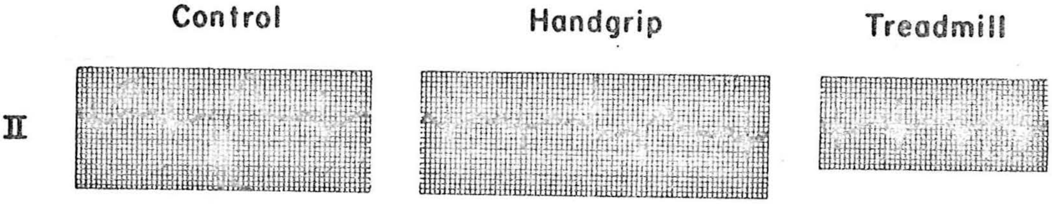
48. *Loc. Cit.*

51. Atkins, J.M., Matthews, O.M., Houston, J.D., Blomqvist, C.G. and Mullins, C.B.: Arrythmias induced by isometric (handgrip) exercise and dynamic exercise. Clin. Res. 19:303, 1971 (Abstr.).

A controversy exists concerning the incidence of arrythmias induced by isometric stress testing in patients with coronary heart disease. Since sudden death in such patients is probably secondary to ventricular fibrillation, it is important to identify those who are potentially vunerable to such attacks. In some studies the incidence of cardiac arrythmias has been higher during dynamic exercise stress testing and in others the incidence has been higher during static exercise stress testing.

The EKG of a 67 year old man with clinically typical angina pectoris who was studied by Kerber and coworkers is shown in Figure 13.

Figure 13



In the control tracing there were a few single premature ventricular contractions. During handgrip exercise multifocal paired premature contractions occurred and during treadmill exercise the premature contractions disappeared. Atkins and coworkers have reported more frequent occurrences of premature ventricular contractions and ventricular tachycardia during isometric exercise than during dynamic exercise.

More studies using isometric testing at 50% maximal voluntary contraction and continuous electrocardiographic monitering are needed to resolve this controversy. It is possible that patients who have ventricular arrythmias during isometric exercise are prone to sudden death, and a study to answer this question needs to be carried out.

C. Evaluation of Left Ven-ricular Function

17. *Loc. Cit.*

18. *Loc. Cit.*

19. *Loc. Cit.*

20. *Loc. Cit.*

21. *Loc. Cit.*

22. *Loc. Cit.*

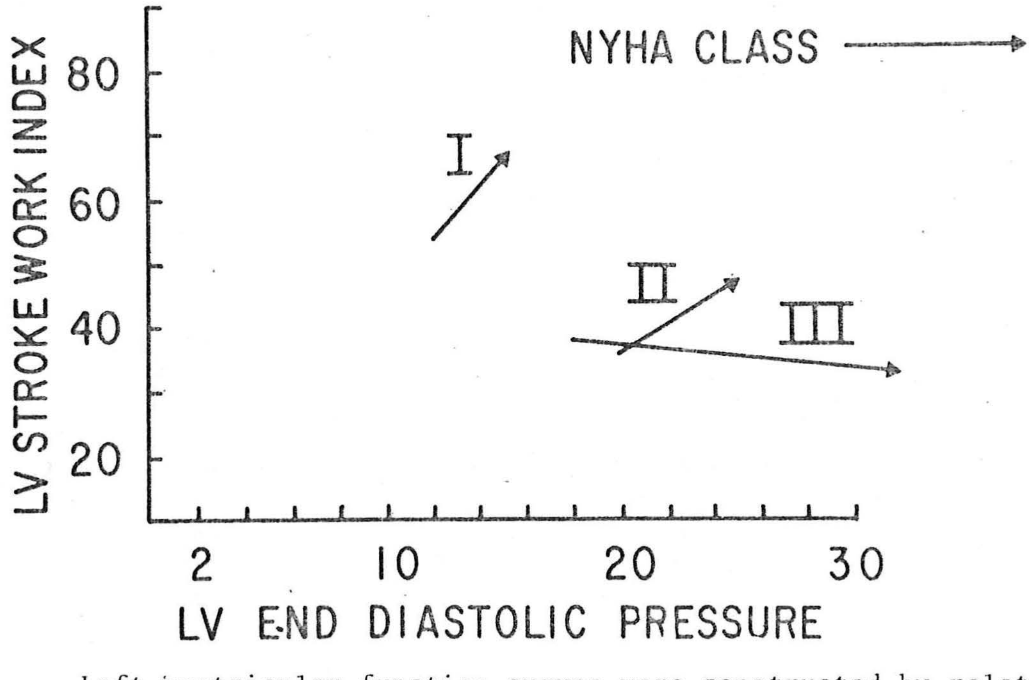
23. *Loc. Cit.*

52. Payne, R.M., Horwitz, L.D., Mullins, C.B.: Comparison of isometric exercise and angiotension infusion as stress test for evaluation of left ventricular function. Amer. J. Cardiol. 31:428, 1973.

53. Krayenbuehl, H.P., Rutishauser, W., Wirz, P., Amende, I., Mehmel, H.: High-fidelity left ventricular pressure measurements for the assessment of cardiac contractility in man. Amer. J. Cardiol. 31:415, 1973.

Isometric exercise appears to have potential value particularly as a test for left ventricular function. In certain respects it may be superior to the angiotension infusion test in this regard. Several groups have now reported that ventricular function curves drawn from values obtained at rest and during handgrip are steep in normal subjects and tend to be less steep or flat in patients with heart disease. An example of this finding from the study of Kovowitz and coworkers is shown in Figure 14.

Figure 14

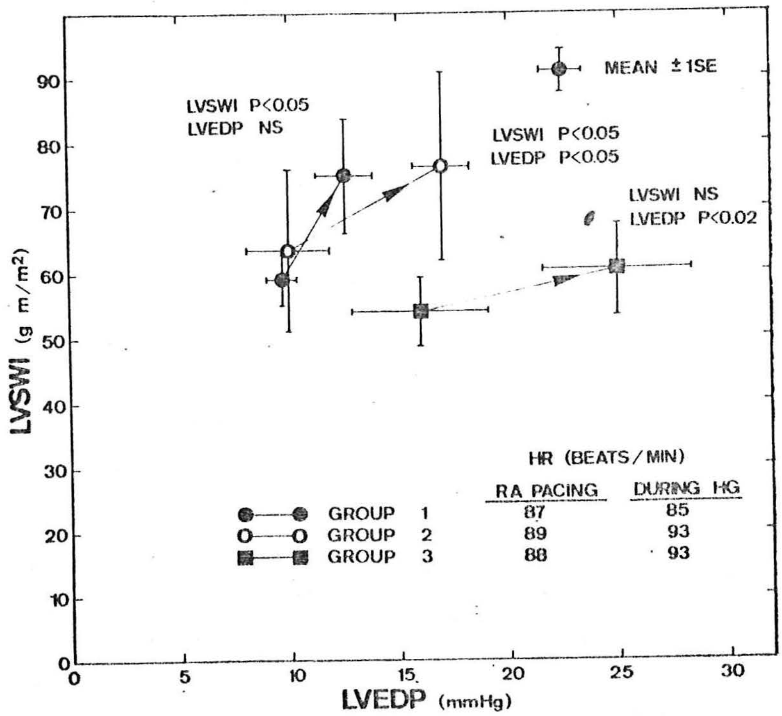


Left ventricular function curves were constructed by relating left ventricular stroke work index to left ventricular end diastolic pressure. The tail of the arrow designates average control values for each group, whereas the arrowhead plots average results during handgrip. The patients in New York Heart Association Class I had a steep rise in stroke work index with little change in left ventricular end diastolic pressure indicating an increase in contractility.

The patients in Class II had a higher resting left ventricular end diastolic pressure and also had a less steep rise in stroke work index and a greater increase in left ventricular end diastolic pressure. The patients in Class III had a slight decrease in stroke work index associated with a marked rise in left ventricular end diastolic pressure. It appears that the left ventricule in Class II and Class III patients has little or no physiological capacity to improve its contractile state and is operating on a depressed Frank-Starling curve. Results are similar when ventricular function is evaluated by simple function curves or by derived indicies which supposedly measure contractile element behavior.

Changes that occur in heart rate during isometric exercise may make evaluation of ventricular function in cardiac patients difficult at times. Therefore, Amende et al kept heart rate constant by electrical pacing during the isometric handgrip test. The results of their study are shown in Figure 15.

Figure 15



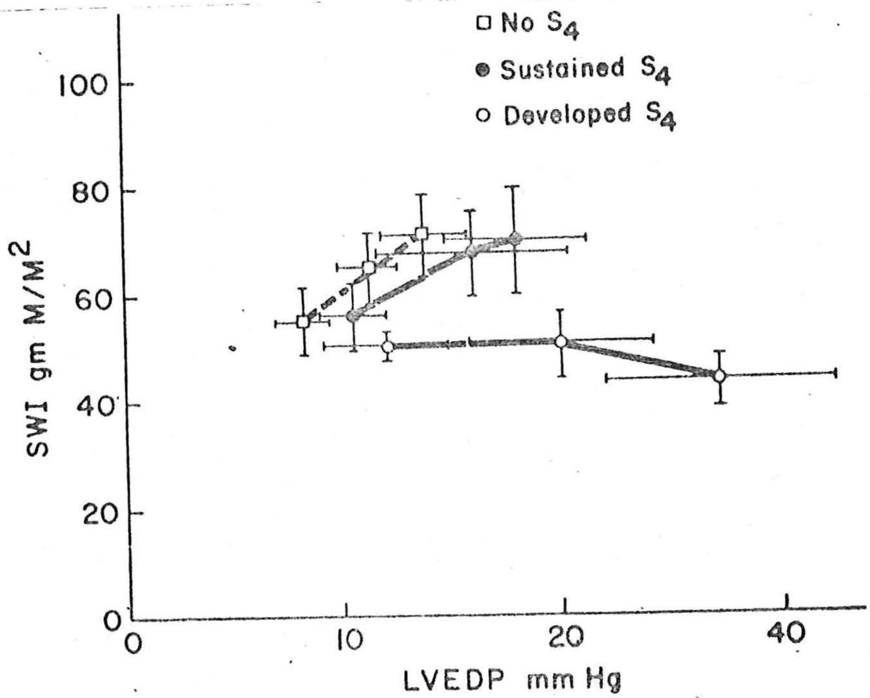
Group I patients had a normal left ventricular end diastolic pressure at rest and responded to handgrip with a significant increase in left ventricular stroke work index with an essentially unchanged end diastolic pressure; they were considered to be normal. Group III patients had an increased left ventricular end diastolic pressure at rest and responded to handgrip with a significant increase in left ventricular end diastolic pressure with an insignificant increase in stroke work index; they were obviously abnormal. Group II patients had a normal left ventricular end diastolic pressure at rest but demonstrated a significnat increase in both end diastolic pressure and stroke work index during handgrip; this group would appear to have abnormal left ventricular function. It is in this identification of patients that may seem to have normal ventricular function at rest, but who develop abnormalities when stressed, that isometric exercise probably has an especially useful clinical role.

54. Cohn, P.F., Thompson, P., Strauss, W., Todd, J. and Gorlin, R.: Diastolic heart sounds during static (handgrip) exercise in patients with chest pain. Circul. 41:1217, 1973.

55. Matthews, O.A., Blomqvist, C.G., Cohen, L.S. and Mullins, C.B.: Left ventricular function during isometric exercise (handgrip): signifiance of an atrial gallop (S_4). Am. Heart J. 88:686, 1974.

Studies have shown that the development of an atrial (S_4) gallop during isometric handgrip signifies a greater depression of left ventricular function than does an atrial gallop at rest that persists during the test. An example of this from the study of Matthews and coworkers is shown in Figure 16.

Figure 16



The patients with no S_4 and those with a sustained S_4 showed a significant increase in stroke work index with little change in left ventricular end diastolic pressure during isometric exercise of 25% and 50% maximal voluntary contraction. The patients who developed an S_4 showed no change and a decrease in stroke work index at 25% and 50% maximal voluntary contraction respectively and a marked increase in left ventrcular end diastolic pressure. This simple procedure may be used as a test of left ventricular function at the patient's bedside.

IV. STATIC EXERCISE IN PATIENTS WITH CARDIOVASCULAR DISEASE

3. *Loc. Cit.*

40. *Loc. Cit.*

From a cardiological viewpoint, isometric exercise is relatively useless and should not be substituted for the use of dynamic exercise in its possible prophylactic and therapeutic value in certain types of cardiac disease. In fact it remains possible that intense static exertion should be avoided in some of these patients.

A. Patients with Systemic Hypertension

56. Kiveloff, B. and Huber.: Brief maximal isometric exercise in hypertension. J. Amer. Geratrics Soc. 19:1006, 1971.

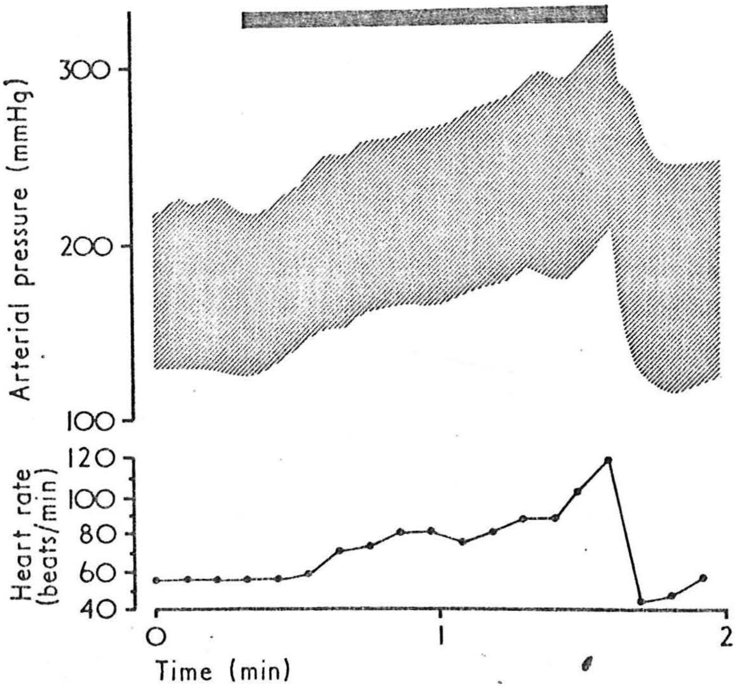
57. Hoel, B.L., Lorentsen, E. and Lund-Larsen, P.G.: Haemodynamic responses to sustained hand-grip in patients with hypertension. Acta med. scand. 188:491, 1970.

58. Ewing, D. J., Irving, J. B., Kerr, F. and Kirby, B.J.: Static exercise in untreated systemic hypertension. Brit. Heart J. 35:413, 1973.

Even though isometric exercise has been advocated as treatment in hypertension, it would appear that this type of activity could be potentially harmful in hypertensive patients. Studies of the cardiovasvular responses to sustained handgrip in hypertensive patients have shown that systolic, diastolic and mean arterial pressure increase markedly with moderate increases in heart rate and cardiac output.

An example of this response in a hypertensive patient studied by Ewing, Irving, Kerr and Kirby is shown in Figure 17.

Figure 17



The patients resting systolic pressure was 220 mm Hg, end diastolic was 130. During isometric exercise at 50% maximal voluntary contraction his systolic pressure rose to 310 mm Hg and diastolic to 142 mm Hg. Similar increases in pressure are seen in normal subjects but the very high levels are achieved in hypertensive patients because of the high baseline level of resting pressure.

Although well documented reports are rare, it seems likely that the high pressures that occur in the arterial system during static exercise in hypertensive patients may have clinical importance. Such elevation in systemic arterial pressure could theoretically precipitate cerebrovascular hemorrhage or left ventricular failure in susceptible patients.

B. Patients with Coronary Heart Disease

4. *Loc. Cit.*

35. *Loc. Cit.*

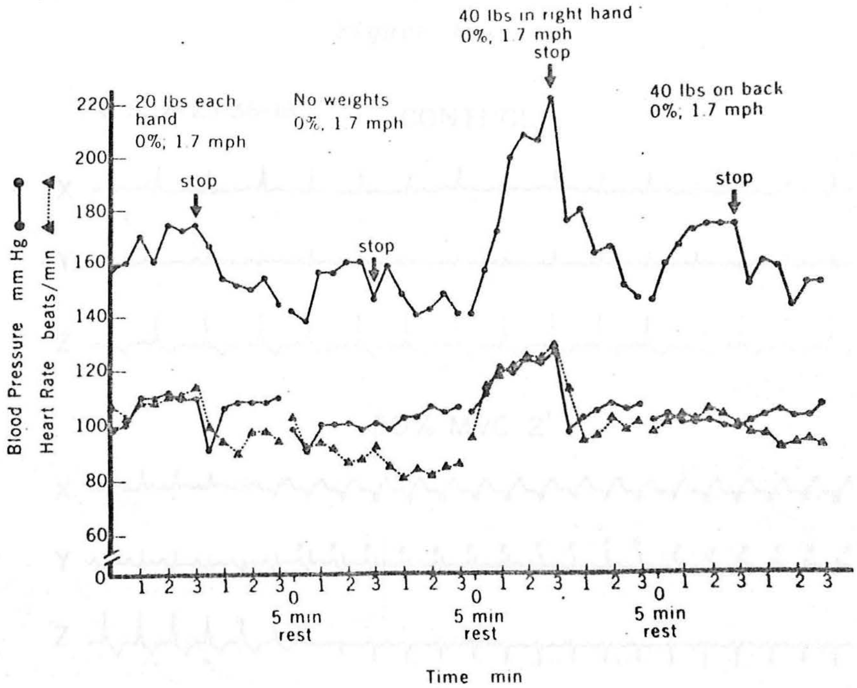
40. *Loc. Cit.*

46. *Loc. Cit.*

51. *Loc. Cit.*

There are many anecdotal reports of untoward events occurring in patients with coronary heart disease during heavy static exercise such as shoveling snow, changing a tire, or straining to open a stuck window. Some patients seem to have their chest pain only with isometric arm work or when isometric arm work is added to dynamic leg exercise. As was discussed earlier it appears that myocardial oxygen demands are increased when static exercise is added to dynamic exercise. The syndrome of "airport angina" might be explained on this basis. "Airport angina" is defined as the severe and unexpected angina a patient experiences at an airport, while walking at a rate usually comfortably tolerated but is carrying a heavy briefcase or suitcase. The response of a patient with coronary heart disease studied by Jackson and coworkers who illustrates this point is shown in Figure 18.

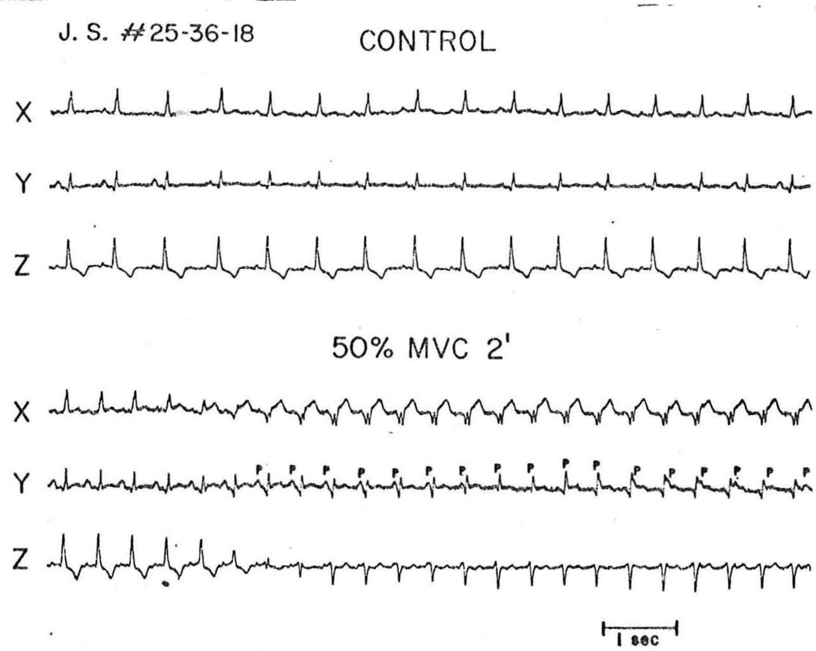
Figure 18



Walking at 0% grade at 1.7 mph without carrying any weights causes little increase in arterial blood pressure or heart rate. Carrying a 40 lb weight on his back while walking causes a small increase in blood pressure and heart rate and this response is further aggravated when the weight is equally distributed in each hand. A marked increase in blood pressure and heart rate occurs when the 40 lb weight is carried in right hand. Thus the double product, as an indication of myocardial oxygen demands, would be higher when the patient was walking with the 40 lb weight being carried in one hand than when carrying the same 40 lbs distributed between his two hands or, even better, on his back.

Sudden death appears to occur more frequently during static exercise then during dynamic exercise. As has been discussed earlier, it appears that static exercise can produce cardiac arrythmias in some patients with coronary heart disease. In the study of Atkins, Matthews, Houston, Blomqvist, and Mullins potentially fatal arrythmias occurred during isometric exercise. An example from their study of ventricuar tachycardia occurring during isometric stress testing is shown in Figure 19.

Figure 19



The Frank lead system is used for recording the electrocardiogram. The control tracing is shown above and that during 50% maximal voluntary contraction held for 2 minutes (50% MVC 2') is shown below. Ventricular tachycardia occurred and spontaneously returned to normal sinus rhythm after handgrip release. As previously pointed out, it is possible that coronary heart disease patients who have ventricular arrythmias during isometric exercise are prone to sudden death. It is important that studies be performed to answer this question.

C. Patients with Depressed Left Ventricular Function

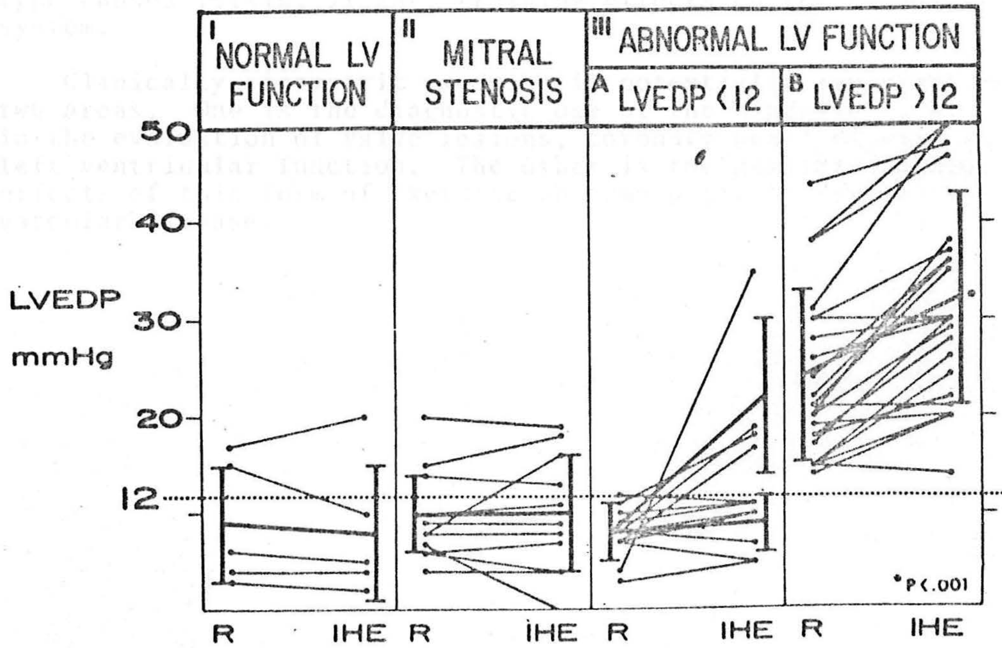
22. *Loc. Cit.*

23. *Loc. Cit.*

40. *Loc. Cit.*

As has previously been discussed, there is little increase in left ventricular end diastolic pressure during isometric exercise in normal subjects or patients with normal left ventricular function. However, marked elevations of left ventricular end diastolic pressure may occur in patients with abnormal left ventricular function. Examples of this are shown in the study by Fisher and coworkers in Figure 20.

Figure 20



The left ventricular end diastolic pressure (LVEDP) is shown at rest (R) and during isometric handgrip exercise (IHE). Little elevation is seen in patients with normal left ventricular function and with mitral stenosis. However, a few patients with a normal left ventrical end diastolic pressure (< 12 mm Hg) at rest and abnormal left ventricular function and many with an elevated left ventricular end diastolic pressure (> 12 mm Hg) at rest and abnormal left ventricular functions have a marked elevation of left ventricular end diastolic pressure during static exercise. If such elevations were maintained for a significant period of time, left ventricular failure and ensuing pulmonary congestion and edema might occur.

V. CONCLUSIONS

In recent years an increased interest has developed in the physiological effects of static (isometric) exercise on the heart and vascular system. This form of exertion imposes a significant pressure load on the left ventricle. Repeated exercise of this type causes little, if any, training effects on the cardiovascular system.

Clinically, isometric exercise is potentially important in two areas. One is the diagnostic use of the handgrip stress test in the evaluation of valve lesions, coronary heart disease and left ventricular function. The other is the possible harmful effects of this form of exercise on some patients with cardiovascular disease.