Effect of Ascending an Ordinary Flight of Stairs on the Work of the Heart

Observations on Normal Individuals and on Patients with Coronary Heart Disease

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Observations of cardiac work were made in normal persons and in patients with coronary heart disease after ascending an ordinary staircase at various rates of speed. Cardiac output was calculated from records obtained with the low frequency, critically-damped ballistocardiograph. The results were compared, for statistical significance, with those noted following descent and after walking for an equivalent distance on the level. It appears that the compensated coronary patient can mount a flight of stairs leisurely without imposing a greatly increased burden of work on the heart. The optimal rate of ascent usually is the one chosen by the individual.

It is common medical practice to advise patients with cardiac disease to avoid the use of stairs when feasible; in the presence of varying degrees of cardiac or coronary insufficiency many are cautioned against ascent at any time. It thus becomes necessary for these persons either to live on the ground floor or to resort to an elevator. Such arrangements may be difficult or impossible to make and frequently are a source of inconvenience and annoyance.

That mounting an ordinary flight of stairs places an added burden of work on the heart and circulation requires no demonstration. But the factors which determine the importance of such an effort for the patient with heart disease are unknown. What is the increment of increase? How does this compare with the changes observed after descending stairs or walking on level ground? What effect on the result have varying rates of performance? What is the duration of the changes in circulatory dynamics? What is their magnitude and duration in cardiac patients in comparison with those seen in normal individuals under similar conditions? These are some of the questions which must be answered if sound principles of guidance are to be followed.

This study is the first of a series in which such matters are to be considered. The present observations were made on normal persons and patients with coronary heart disease after performing various types of exercise on a staircase and walking on the level. It is planned to make similar studies in patients with other etiologic types of cardiovascular disease and also after other forms of effort, such as ascending a ramp.

Clinical Material and Procedure

Observations were made on 5 normal persons ranging in age from 41 to 77 years of age (average, 54.6 years), and in 5 patients with coronary heart disease ranging in age from 44 to 65 years (average, 55.2 years). Each group was composed of 4 men and 1 woman. Two of the patients had healed myocardial infarcts; one of them had been in congestive heart failure and was taking maintenance doses of digitoxin as well as a diet low in salt content. The diagnosis of coronary heart disease was confirmed in the other patients by the presence of a positive anoxemia test; in 2 of them, an electrocardiogram taken during a spontaneous attack of anginal pain showed alterations characteristic of acute coronary insufficiency.
A complete history was taken and a physical examination, electrocardiogram, 2 meter film of the heart and a hemoglobin estimation were made in each subject.

The observations consisted of the following: (1) determination of cardiac output four times at 3 minute intervals during a resting period and during the period of recovery after the exercise, at intervals of 1, 2, 3, 5, 7, 9, 12, 15, 20, 25 and 30 minutes; (2) recording of systolic and diastolic blood pressures and of heart rate at one minute intervals throughout. The cardiac output was calculated from records obtained with the use of the low frequency, critically-damped ballistocardiograph designed by Nickerson and Curtis and tested by comparison with the direct Fick method by Nickerson, Warren and Brannon. Lead II of the electrocardiogram was recorded simultaneously with the ballistocardiogram. The records were made without any attempt to control respiration. In the course of the work, more than 4000 ballistocardiograms were taken.

The exercises employed were of three types: (1) walking up one flight of stairs; (2) walking down one flight of stairs; (3) walking down the hall and back to the laboratory for an equivalent distance. All tests were carried out under basal conditions and after the subject had rested for 30 minutes in the recumbent position on an inflated air mattress on the ballistocardiographic table. Following the resting period, the subject was transported by wheelchair and elevator to the bottom or top of the staircase for the test of the day. The blood pressure cuff and electrocardiographic electrodes remained on the extremities during the exercise to facilitate the speed of making the observations during the recovery period. All obstructions, such as closed doors and other persons, were removed from the path of the subject being tested.

The three types of exercise were repeated twice at the individual's own rate of performance. The effect of increasing or decreasing this rate was determined twice for each type of exercise in the 5 normal persons and in 3 of the cardiac patients. In no instance was one test given in the course of 24 hours.

The staircase was of the conventional variety and was in the Medical School building. It consisted of 2 sections of 11 treads each separated by an 8 foot landing. Each tread measured 11 inches in width, with a rise of 7 inches. The distance from the first step to the ballistocardiographic table was 70 feet and from the last step to the table was 34 feet. The time elapsed between the conclusion of the exercise and the beginning of the observations on the table was less than 30 seconds.

A control maneuver was performed in duplicate during which the same observations were made as already described. However, instead of performing the exercise, the subject was transported by wheelchair and elevator up or down one floor and returned to the ballistocardiograph without leaving the chair. He then stood erect for 30 seconds before resuming the recumbent position on the table. In this way the effects of all factors minus the prescribed exercises, could be determined.

The cardiac work was calculated according to the formula

\[ CW = CO \times MP \]

where \( CW \) = cardiac work, \( CO \) = cardiac output (liters per minute), and \( MP \) = mean pressure (diasstolic blood pressure + \( \frac{1}{2} \) pulse pressure, in mm. Hg).

**Fig. 1.** Averages of changes in circulatory dynamics in 5 normal persons after ascending a flight of stairs at each individual's own chosen rate. Arrow marks ascent.

**RESULTS**

These are shown in figures 1 to 6. They are expressed as averages for the various groups under consideration; the figures have been submitted to statistical analysis.* It is clear that, although the number of observations runs into thousands, the number of subjects is relatively small. In order that the changes associated with exercise shall be of significant magnitude it is necessary that they should be comparatively large so as to cover the great variations within individual performances as well as varia-

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manifest, the lack of significance cannot be stressed, for negative conclusions might not be verified in a larger experience. In a few instances, borderline values were obtained and attention will be called to them in the proper

places. For each group the changes are expressed as increases over the levels observed in the resting period for that particular group;

Fig. 2. Averages of changes in circulatory dynamics in 5 patients with coronary heart disease after ascending a flight of stairs at each individual's own chosen rate. Arrow marks ascent.

Fig. 3. Averages of changes in circulatory dynamics in 5 normal persons after descending a flight of stairs at each individual's own chosen rate. Arrow marks descent.

Fig. 4. Averages of changes in circulatory dynamics in 5 patients with coronary heart disease after descending a flight of stairs at each individual's own chosen rate. Arrow marks descent.

Fig. 5. Averages of changes in circulatory dynamics in 5 normal persons after walking on the level at each individual's own chosen rate. Arrow marks the walk.

Fig. 6. Averages of changes in circulatory dynamics in 5 normal persons after ascending a flight of stairs at each individual's own chosen rate. Arrow marks ascent.

limitations between individuals. When significant differences are apparent they are of importance; when the differences are not significant although
by so doing, the effects of the exercise alone are measured.

Ascent of Stairs. In the normal subjects, there occurred a significant increase in cardiac work, stroke volume and heart rate. The cardiac work increased 226 units* (54 per cent), the stroke volume 26 cc. (32 per cent) and the heart rate 8 beats (13 per cent). In the patients with coronary heart disease there was a significant increase in pulse pressure, cardiac work and stroke volume. The pulse pressure rose 18 mm. Hg (27 per cent), the cardiac work increased 323 units (75 per cent) and the stroke volume 30 cc. (44 per cent). The change in heart rate was small, with an average increase of only 9 beats per minute; this amount is not statistically significant.

The notable increases occurred in cardiac work and, to a somewhat lesser degree, in stroke volume in both normal subjects and cardiac patients. The changes were greater in the cardiac group but the differences between the two groups were not larger than might have been caused by chance variation.

Descent of Stairs. Although there were increases in the figures obtained for all four factors observed, these were not statistically significant in either the normal or the cardiac group; nor were there significant differences between the two groups. It should be noted, however, that in the normal group cardiac work increased 56 units (12 per cent) and in the cardiac group it increased 148 units (42 per cent). Similarly, in the normals, the stroke volume increased 5 cc. (2 per cent) and in the cardiaics 12 cc. (26 per cent). The increases were thus consistently greater in the cardiac group.

Walking on Level Ground. In the normal group, there was a borderline increase in pulse pressure and in the cardiac group, a similarly equivocal increase in stroke volume. The changes were not striking, either by themselves or on comparison of the differences between the two groups.

Control Maneuver. There were no significant increases in either group in any of the circulatory factors measured, nor were there noteworthy differences between the two groups. The changes throughout were numerically relatively small.

Varying the Rate of Performance of the Exercises. The chosen rate of speed of carrying out ascent, for the normals, was, on the average 29.6 seconds, with a range of 25 to 37; for the cardiaics, the average was 36.4 seconds with a range of 25 to 47. For descent, the average time for the normals was 26.7 seconds, with a range of 19 to 34; for the cardiaics, it was 31.1 seconds with a range of 23 to 37. For walking on

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* The unit of cardiac work is obtained by multiplying the figure for cardiac output, in liters, by that for mean pressure, in mm. Hg.

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**Figure 6.** Averages of changes in circulatory dynamics in 5 patients with coronary heart disease after walking on the level at each individual’s own chosen rate. Arrow marks the walk.
scent, the fastest average rate was 26 seconds, which was slowed to 40 seconds for later observations. The normals, then, all slowed up by request; the cardiaics were less uniform in their chosen rates of performance and were asked to accelerate or retard as much as 20 per cent in either direction.

Although the average differences were not statistically significant, in most instances cardiac work was minimized when, in the ascent of stairs, both normals and cardiac patients were permitted to proceed without guidance. The individual, either as a result of habit or, in the case of the cardiaics, because of previous instruction, instinctively chose what for him was the optimal rate. Hickam and his group, using both the Nickerson ballistocardiograph and the Fick method after cardiac catheterization, and Wolff and his associates, using the same ballistocardiograph, have observed that ordinary physical exertions of everyday life performed during periods of relaxation impose little extra work on the heart, whereas, when carried out under emotional stress, they cause an increase in cardiac output. It appears from our experience that a conscious effort to modify the rate of performance of an exercise, even slightly, also may result in an augmentation of cardiac work.

**Duration of Changes in Circulatory Dynamics after the Exercises.** In the normal group the return to resting levels was completed at the end of the third minute during the period of recovery. The three-minute observation was chosen, therefore, as a reference point for measuring the duration of the increases noted. In the coronary group, after ascent, there was a significant delay beyond three minutes in the return to average resting values for cardiac work and a similar lag, of borderline significance, for stroke volume. However, in both instances, the delay was only a matter of a few minutes (fig. 2). There was no significant delay in the return to resting levels after the other exercises, in either group of subjects. In the normals, on descent and after walking on the level, there was a tendency for cardiac work to fall slightly below resting levels at the time of the three minute observation; this did not occur in the cardiac patients.

**Discussion**

Numerous studies have been made of cardiac output and cardiac work after effort, using a variety of methods. For the most part, the exercises employed have been quite vigorous and have been performed at rates of speed fixed by the investigator. In the present study, the exercises used were moderate and, in the basic experiments, were carried out at a rate chosen by the individual subjects. Previous results and our own are not, therefore, strictly comparable. In addition, as far as can be determined, in no other study have statistical methods been applied to determine the significance of observed differences from control levels or of variations between normal individuals and patients with cardiovascular disease.

In this investigation, also, the usefulness of the low frequency, critically-damped ballistocardiograph has been demonstrated for making possible a large series of observations of cardiac output in each subject. The determinations of stroke volume and cardiac output were made on ballistic recordings taken without any constraint on the respiration. For some individuals with cardiac disease the ballistocardiographic patterns deviate from the normal form and the results for the stroke volume may differ somewhat from the absolute values. However, the relative changes in stroke volume are given quite accurately. The accuracy of the method for relative change was originally demonstrated by Nickerson, Warren and Brannon and is further supported, in the present study, by the manner in which the curve for stroke volume parallels that for pulse pressure.

In dealing with group averages in a small series, it is inevitable that a wide range of individual variability will reduce the incidence of statistical significance of even comparatively large numerical differences between the groups considered. Under the conditions of these tests, it was observed that there was considerable individual variation.

The levels for the averages for cardiac work and for stroke volume during the resting period were lower for the cardiac group than for the normals in every series of comparisons. While
the difference was often considerable it cannot be termed significant in view of the large individual variations exhibited by both groups. Thus, although no symptoms or signs of congestive failure are present, the functional capacity of the heart, even at rest, apparently is somewhat diminished in patients with coronary heart disease. A similar observation was made by Starr and Wood, using the ballistocardiographic method, and according to these observers, cardiac work, in the chronic form of this disorder, tends to decrease as the condition advances.

This study was undertaken primarily to obtain information of practical value in the guidance of patients with coronary heart disease with respect to the use of stairs. The inferences to be derived from our observations are somewhat at variance with current beliefs. It appears that ascending an ordinary flight of stairs at an individual's own chosen rate of speed, which is commonly a leisurely one, does result in a significant increase in the work of the heart. This is due chiefly to augmentation in cardiac output, since there is but little change in the heart rate. The differences between ascent on the one hand, and descent and walking on the level for an equivalent distance on the other, are in general, rather large numerically but are not, in all cases, statistically significant because of the individual variations. The amount of cardiac work observed in descent is, as might be anticipated, intermediate between that involved in ascent and that required for walking on the level. The absence of any notable increase in the rate of the heart following all three types of exercise, in both normal and cardiac groups, is also worthy of repeated mention. None of the 5 patients experienced discomfort of any sort during or following the tests performed in the course of this study.

SUMMARY AND CONCLUSIONS

In a series of 5 normal persons and 5 patients with coronary heart disease, observations were made after ascent of an ordinary flight of stairs, descent of these stairs and walking for an equivalent distance on the level. The low frequency, critically-damped ballistocardiograph was used to measure cardiac output. Cardiac work, stroke volume, pulse pressure and heart rate were recorded. The results were submitted to statistical analysis.

The ascent of stairs does not impose a greatly increased burden of work on the heart. The response of the patient with compensated coronary disease is not significantly greater, following this exercise, than after descent and is only slightly greater than after walking for an equivalent distance on the level. The stress is of relatively brief duration. Obviously, in the presence of congestive failure or if anginal pain occurs during the exertion, stairs should be avoided. Otherwise, the coronary patient may take them leisurely and preferably at a pace which he finds agreeable. Deliberate retardation, like hurry, may augment cardiac work.

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REFERENCES


