Exercise and Intermittent Claudication

I. Effect of Repetition and Intensity of Exercise

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SUMMARY
Four men with arteriosclerosis obliterans (ASO) were exercised on a treadmill on 4 different days to determine their maximal walking time (MWT) and the point at which their claudication pain (CPT) began. Each subject was exercised at 60%, 75%, and 90% of his MWT to determine the effect of work intensity on the systolic blood pressure at the ankle (AP). To measure the effect of exercise repeated on the same day, each subject walked five times each day on 4 different days at each of the three workloads. After each subject completed the required number of walks, his MWT was again measured on 4 separate days (one subject was retested only once) to determine whether it had changed.

In every case the greatest reduction in AP occurred after the initial maximal walk but the submaximal intensities caused different responses in the different subjects. With repetition of exercise each subject displayed a progressive increase in either the AP level taken 2 minutes postexercise or the rate of recovery of AP to the pre-exercise level. There were significant increases in MWT, in CPT, and in the resting and postexercise AP levels in some of these subjects. This was most probably due to increased collateral circulation before, during, and after exercise.

Additional Indexing Words:
Arteriosclerosis obliterans  Systolic blood pressure at ankle
Maximal walking time  Increased collateral circulation  Claudication pain

Introduction
Arteriosclerosis obliterans (ASO) is usually a slowly progressing disease, of which the patient is not aware until the metabolic requirements of the exercising muscle can no longer be satisfied. Limb survival with arterial occlusion is possible because of the collateral arteries that bypass the obstruction. Since these bypassing conduits are high resistance pathways, there is a limit to the amount of blood that can be delivered to the exercising muscle; this results in ischemia. The most satisfactory method of restoring the exercise response to normal has been reconstructive arterial surgery. While this method of therapy is frequently successful, it is applicable to only a relatively small number of patients with ASO.

If surgery is not performed, there is little else the physician can offer his patient for the relief or improvement of the claudication. Although vasodilator drugs have been used, their efficacy is open to dispute and they are not generally considered to be effective in this regard. Frequently, exercise is prescribed with little rationale other than the hope that it may “stimulate collateral development.”

The authors’ interest in the problem of exercise and its possible therapeutic effects was stimulated by clinical observations. Some patients reported that they felt they could

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walk farther after recovering from the pain of claudication brought on by an initial walk in the morning. There is a problem, however, in interpreting any change in either the time of onset of pain or the distance walked by patients with claudication because of the absence of a suitable, objective method for verifying clinical impressions.

Ejrup, Winsor and associates, and Strandness and Bell have shown in patients with ASO that the systolic pressure at the ankle (AP) falls often to unrecordable levels and that a prolonged time is required for it to return to the pre-exercise level. This reduction in AP would appear to be the result of the marked vasodilatation that occurs in the muscle along with the high resistance to flow at the collateral vessels. Since the collateral vessels cannot provide enough blood to prevent ischemia, the pressure distal to the occlusion falls and blood is shunted from the foot to the exercising muscle. The magnitude of the fall in AP appears to reflect the extent of ischemia and the functional capacity of the collateral arteries. The amount of time required for the AP to return to the pre-exercise level reflects the degree of postexercise hyperemia of the muscle. Since it has been shown that improvement in claudication has been accompanied by a lesser reduction in AP after exercise and a faster recovery time, this test was considered suitable to follow the course of a patient's claudication.

With use of this AP response to exercise as the objective test, a study was done on a series of patients with intermittent claudication secondary to ASO. The first part of the study was designed to test the effect of repetition and intensity on the AP response to exercise. This was considered a prerequisite for devising a worthwhile program to evaluate the effects of physical training.

**Methods**

The volunteers for this study were four men ranging in age from 52 to 73 years with moderate ASO and no rest pain or tissue necrosis. Subject L. A. was a 52-year-old armored carrier guard with a relatively mild history of bilateral claudication secondary to occlusion of the superficial femoral arteries. Subject J. R. was a retired 69-year-old with a 4-year history of claudication secondary to a right superficial femoral artery occlusion. Subject N. R., a 72-year-old retired minister, had a 2-year history of claudication from a right popliteal artery occlusion. The fourth subject, G. W., was 65 years old and had an 8-year history of claudication due to a left superficial femoral artery occlusion and bilateral iliac stenoses. Diagnosis of ASO was clinically established by a history of claudication, by a change in palpable pulses below the area of involvement, and by measurement of segmental limb pressure gradients.

Each man was given a physical examination to determine whether there were any contraindications to his participation. This included monitoring the electrocardiographic response during a maximal walk on the treadmill at 2 mph up a 12% grade (subjects L. A., J. R., and G. W.) or up a 20% grade (subject N. R.)

Systolic blood pressure at the ankle (AP) was measured in the supine position with a mercury-in-silastic strain-gauge plethysmograph. This silastic gauge was placed around the second digit and a sphygmomanometer cuff was wrapped around the ankle of the leg with the more severe claudication (fig. 1). AP was measured by noting the point at which digital pulses reappear after occluding arterial inflow with the pneumatic cuff and was recorded prior to and at 2-minute intervals after each walk on the treadmill. After the maximal walks, AP was recorded until it returned to the initial resting baseline value. Heart rate and arm blood pressures were recorded prior to and 1 minute after each treadmill walk.

The maximal walking time (MWT) of each subject was determined once a day on 4 different

**Figure 1**

Recording of ankle systolic blood pressure by a mercury-in-silastic strain-gauge plethysmograph. Strain gauge was placed on second digit in the present study.
days; during these walks, the time of onset of claudication pain (CPT) was also noted. This measured the variability of responses within each subject, who also served as his own control.

To determine the effect of work intensity on the AP response, each subject was exercised at 60, 75, and 90% of his MWT. The order in which these were done was randomly assigned to each subject, who walked on the treadmill five times (repetitions) each day on 4 different days at each of the three intensities. AP was recorded during the 10- to 15-minute intervals between repetitions.

After each subject had walked the prescribed number of times (five walks per day for 12 days) his MWT, CPT, and AP responses were again recorded on 4 different days to see whether there had been any change.

Data from each subject were analyzed by an analysis of covariance technique* with AP as the dependent variable and time after exercise as the covariate. With this technique, the effect of workload on AP could be determined while the effect of repetition was kept constant, and vice versa. Grouped data were analyzed in this way, except that the effect of the subjects on the variation in the AP response was also determined. In comparing the AP responses to the initial and final maximal walking tests, a multiple regression technique* was used. This estimated the slope and intercept of the average line formed by each set of recovery AP values. Where appropriate, F-tests and t-tests were used to measure the magnitude of the observed differences.

Results

Subject L. A. had a resting AP value of 126 mm Hg and walked 9:31† (2 mph, 12% grade) on the treadmill before stopping due to the claudication pain which began at 2:14. His AP decreased 20% to 101 mm Hg and returned to the resting level within 8 minutes.

After the first walk at 90% MWT, his AP dropped 9% and approached the resting level within 10 minutes (fig. 2A). With each successive walk there was less of a reduction in AP so that after the fifth walk AP fell only 2%, returned in 4 minutes, and remained slightly above the resting level. Walking at 60% and 75% MWT resulted in similar responses (fig. 2B and C), that is, after the third walk his AP response was essentially normal.

MWT increased significantly from 9:31 to 24:32 (P < 0.001) and there was little change in CPT (2:14 to 2:24). The resting AP level

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*Data were analyzed by the University of Washington computer center's IBM 7094 using the Biomedical Computer Programs, edited by W. J. Dixon, Department of Preventive Medicine and Public Health, UCLA.

†Duration of time walked will be indicated throughout in this way—9:31, that is, 9 min 31 sec.

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Recovery of ankle systolic blood pressure after exercise. Effect of various percentages of subject's maximum. The horizontal line at 100% denotes the mean resting ankle pressure; other lines denote the recovery of ankle pressures after each work intensity. 100% T1 is the first test of maximum walking time and 100% T2 is the final test.

was increased from the initial value of 126 mm Hg to 142 mm Hg (P < 0.01), and his arm blood pressures were 119/71 and 125/75, respectively.

Analysis of covariance revealed a significant effect of repetition on the AP responses at the various workloads (P < 0.01). There was also an effect on the different workloads on the overall AP responses (P < 0.01). This is partially seen in figure 3, where the AP response after the first walk at each exercise intensity is plotted. The initial maximal walk (100% T1) caused a greater reduction in AP than did the maximal walk at the conclusion of the study (100% T2). Both of these resulted in greater reductions than did any of the submaximal walks. Although each submaximal workload resulted in the same percentage drop in the AP taken 2 minutes after exercise, more time was required to return to the resting baseline after walking at 90% MWT.

Subject J. R. entered the study with a MWT of 2:36 (2 mph, 12% grade) and his pain began at 1:36. His resting AP level of 103 mm Hg decreased to 8 mm Hg after this maximal walk and did not fully recover until 18 minutes had passed.

With each walk of 60% MWT, at which intensity he did not usually experience pain, his AP decreased to 55% of the resting level (fig. 4A). There was a more rapid rate of recovery after each successive walk, leveling off with the fourth and fifth walks. At 75% MWT the first walk resulted in a greater fall in AP but the response after the last 3 walks at 75% MWT was similar to that after the last 2 or 3 walks at 60% MWT (fig. 4B).
repetition effect can also be seen after walking at 90% MWT (fig. 4C). The greatest reduction in AP occurred after the first walk, and with each successive walk there was less reduction and a shorter recovery time.

Subject J. R. was retested maximally only once, at which time his MWT increased to 4:50 with pain beginning at 2:12. There was no difference in his resting AP level or in his arm blood pressures. Since he was retested only once, it was not possible to determine statistically whether there were any significant changes in his AP response. Visual inspection of figure 5, however, shows little difference in rate of recovery but less reduction in AP after a maximal walk that was twice as long as his initial MWT. Further testing was no longer possible because J. R. had an acute thrombosis of his right popliteal artery, which required hospitalization. Following this occlusion his resting AP decreased to 50 mm Hg.

Figure 5 shows a definite gradation of AP response to the exercise intensity after the first walk. Because of the repetition effect at each workload \((P < 0.01)\), there was little difference in the effect of intensity on AP when these responses were grouped together.

Subject N. R. had a resting AP of 63 mm Hg, which dropped to unrecordable levels for 4 minutes after a MWT of 10:53 (2 mph, 20% grade). Claudication pain began at 2:30, and it took 18 minutes for the AP to return fully to the resting level.

When subject N. R. exercised at 75% MWT, his AP decreased to unrecordable levels for 4 minutes after the first walk and for only 2 minutes after the second walk (fig. 6A). There was less of a drop in AP and a faster recovery rate after each successive walk. A repetition effect was also noticeable after walking at 60% MWT, and the shortest recovery time again occurred after the last walk (fig. 6B). Although the initial decrease

\[ \text{Figure 5} \]

Recovery of ankle systolic blood pressure after exercise. Effect of various percentages of subject's maximum. Refer to figure 3 for explanation.

\[ \text{Figure 6} \]

Recovery of ankle systolic blood pressure after exercise. Effect of five consecutive walks at three work intensities. Refer to figure 2 for explanation.
in AP was slightly less after each successive walk at 90% MWT, the recovery rates from the second, third, and fourth walks were superimposed on one another (fig. 6C). Recovery time was again shortest after the last walk.

When the MWT of subject N. R. was retested, he had a significant rise in his resting AP level from 63 to 82 mm Hg ($P < 0.001$) but no difference in the blood pressures taken at the arm (102/61 and 106/64, respectively). There was also a significant increase in MWT from 10:53 to 15:14 ($P < 0.001$) with little change in CPT (2:34 to 2:47). After the second set of maximal walks, the AP dropped to unrecordable levels for only 2 minutes as compared to 4 minutes initially (fig. 7). Multiple regression analysis showed this difference in AP reduction to be highly significant ($P < 0.001$) but there was little difference in the rate of recovery. Analysis of covariance revealed a significant effect of both repetition and workload on AP response to exercise ($P < 0.01$).

Subject G. W. had a resting AP level of 104 mm Hg and a MWT of 3:21 (2 mph, 12% grade), with pain beginning at 2:05. After the maximal walks on the treadmill, his AP fell to unrecordable levels for 4 minutes and took 24 minutes to return to the resting level.

After the first walk at 75% MWT there was a marked drop in AP but with each successive walk there was less of a reduction (fig. 8A). The same pattern was present after the walks at 90% MWT, with a wide difference in AP response between the first and last walks (fig. 8B). On the other hand, there was little difference in the subject's response after each walk at 60% MWT (fig. 8C). It is of interest that he did not have pain during any of the walks at 60% MWT.

At the time his MWT was retested, there was no change in his resting AP level or in his arm blood pressures. There was a significant
increase in his MWT from 3:21 to 7:13 ($P < 0.01$) and in his CPT from 2:14 to 3:19 ($P < 0.01$). As seen in figure 9, the fall in AP after the second set of maximal tests was significantly less ($P < 0.001$) but there was little difference in the rate of recovery. Statistical analysis revealed that the effects of both repetition and workload were significant for this subject ($P < 0.01$).

Analysis of grouped data showed a highly significant difference among the four subjects in their AP responses to the different workloads and repetitions ($P < 0.001$). Likewise, there was a significant effect of intensity and repetition of exercise on the AP responses of the entire group ($P < 0.001$). None of the four subjects exhibited any marked differences in rate of recovery between the initial and final maximal tests, but they all had less of a reduction in AP after the final tests.

Discussion

There were marked differences in disease severity in these subjects as evidenced by their AP responses and MWT. One thing that all subjects had in common, however, was that repeated exercise had an effect on their AP response.

The most likely explanation for the improvement in AP response to successive walks is that a progressive dilatation of the collateral circulation occurred; this decreases the resistance to flow, resulting in the delivery of an increased volume of blood to the exercising muscle. Improvement in collateral circulation is further suggested by observations on N. R. After the first two walks at 75% MWT his AP fell to unrecordable levels, whereas after the third walk, during which a generalized perspiration first appeared, it dropped to 25% of the resting level (fig. 6A). Similarly, his AP dropped to unrecordable levels after the first walk at 90% MWT but not after the second walk when he perspired (fig. 6C). This occurred on each of the 4 days that N. R. walked at 75% and 90% MWT. This is in agreement with results of nerve-blocking experiments by Love and Shanks, who found a close relationship between the time of onset of sweating and the time of onset of increased blood flow caused by vasodilator nerves acting on the vessels.

There is a suggestion that workload had to be of sufficient intensity to elicit the effect of repetition. The initial reduction in AP was not different at 60% MWT for either G. W., who had no pain at this workload, or J. R., who had occasional pain (figs. 4A and 8C). The effect of repetition was also least at 60% MWT for L. A. (fig. 2B).

It was not possible to determine the relative effects of each workload on the AP of the group, since there was so much individual variation. However, the initial maximal walks had the greatest effect on the reduction and recovery of the AP for each subject (figs. 3, 5, 7, and 9). Another reason it was difficult to determine the effect of work intensity on AP response was that each subject's MWT was increasing during the study. Thus, a percentage of the initial MWT was changed since the MWT itself was changing. This probably had its largest influence on the AP responses at the last workload each subject did before his MWT was retested. This training effect may have influenced the subject's ability to adapt to the exercise and, thus, may have modified the effect of repetition. Changes in the resting and postexercise AP levels caused by training also made it difficult to analyze results from an experiment designed to measure changes in only one factor at a time.

The rise in resting AP in subjects L. A. and N. R., who also did more work in absolute
terms, could not be explained by a parallel increase in blood pressures recorded at the arm and was probably due to an increase in collateral circulation. This was reflected, too, in the significant increases in MWT of L. A., N. R., and G. W. (probably also in J. R., who doubled his MWT on the one retest) and especially in the marked increase in CPT noted in G. W. and J. R. (significant for G. W.). Even though these subjects walked significantly farther as a result of these exercise sessions, there was less reduction in AP recorded 2 minutes after exercise; significantly so for L. A., N. R., and G. W. Increased collateral circulation with its resultant increased blood flow appears to be the most logical explanation.

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References

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