Swell-Preventing Effect of Intermittent Exercise on Lower Leg during Standing Work

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Abstract: This study investigated the effectiveness of several possible exercises for performance during standing work in order to prevent lower leg swelling and relieve subjective complaints. Volume changes in the lower leg were measured using bioelectrical impedance plethysmography in 13 healthy male subjects aged 23–36 years. Subjective complaints of leg pain, leg dullness and whole body fatigue were also recorded. Measurements were performed at two-minute intervals during a one-hour period of standing with insertions of one-minute of exercise every 10 min. The exercises were knee-bending, foot-stepping, walking, and heel-raising. The change rates of impedance over one hour were 2.2%, 4.0%, 4.6%, and 6.3%, respectively, indicating that leg volume was increased under all exercise conditions. Among exercises, the swell-preventing effect of knee-bending was strongest, and that of heel-raising was weakest. Heel-raising also yielded the highest number of subjective complaints. Knee-bending, which uses the thigh and calf muscles simultaneously, was considered the most effective for suppressing lower-leg swelling and minimizing subjective complaints.

Key words: Lower leg, Swelling, Workload, Standing, Exercise

Introduction

Although the introduction of the machine has greatly reduced the manual material handling in the workplace, it has also led to an increase in simple standing and sitting, as workers are obliged to monitor computers and production equipment. The new work-style has subsequently favored standing over sitting, since many Japanese companies have succeeded in improving productivity with the “just in time” method, which emphasizes standing work. Such increase of standing work causes leg swelling, and it is reported that long-term leg swelling increases the risk of developing pathological reactions such as varicose vein, thrombosis and pulmonary embolism1.

In the standing posture, increased transcapillary filtration and reduced reabsorption of tissue fluid due to increased hydrostatic pressures in the blood vessels of the leg lead to an increase in the extravascular fluid volume of the lower leg. The muscle exercises also have a swell-preventing effect2–3, which is considered the result of such factors as reduced venous pressure4–6, enhanced lymph flow7–8, and increased muscle tissue pressure9 during muscle contraction. Stick et al. reported that thigh volume increases during cycle ergometer exercise7. This increased thigh volume is caused by a fluid shift, which in turn appears to be caused by increased osmolality8 in exercising muscle. The muscle exercise has these conflicting factors. The leg swelling is determined by their balance.

For reason of the many factors mentioned above, it is unclear what kind of exercise should be inserted in order to reduce leg swelling during standing work. Previous studies have mentioned the simple relationship between quiet standing and a single exercise, such as the cycle ergometer exercise or heel-raising, but no study has been made of the difference in leg swelling among the various exercises. We therefore examined the differences in leg volume and in
subjective complaints among four types of exercises over a one-hour period of standing.

Materials and Methods

Subjects
This study was conducted on thirteen healthy male subjects, aged 23 to 36, who showed no evidence of venous valvular incompetence or edematous disease. The subjects’ age, height and weight were (mean ± SD) 25.0 ± 3.6 years, 173.6 ± 5.6 cm and 68.9 ± 10.9 kg, respectively.

Experimental protocol
The experiments were started after the subjects had sat for 30 minutes, and following 2 minutes standing to avoid the initial volume drift caused by quick posture change. The subjects stood for one hour with their feet placed 30 cm apart on parallel lines. They were required to keep their legs in the same position except during the one-minute periods of exercise inserted every 10 min. One of the following four types of exercise was performed during the one-hour trial:

1) Knee-bending: The subject stretched and bent the knee in the standing position.
2) Foot-stepping: The subject walked in place.
3) Walking: The subject walked back and forth along a 3 m straight line.
4) Heel-raising: The subject stood raising and lowering the heel.

All subjects carried out four trials of each exercise. Each subject performed one trial per day in order to avoid any possible influence by the previous trial. The speed of each exercise was not regulated to observe the self-control by the subjective complaints. Each exercise was recorded on videotape and the exercise speed was counted.

Plethysmographic measurements
Lower-leg swelling was measured by the four electrode bioelectrical impedance method with the apparatus we developed. The apparatus measures the absolute value of the impedance. The two detecting electrodes (Ag/AgCl electrodes, Vitrode M-150, Nihon Kohden Corporation, Japan) were fixed at the medial side of the right lower leg with a 15 cm interelectrode distance. The measuring current was 200 µArms and its frequency was 5 KHz. The impedance was measured every two minutes.

Subjective complaints
A subjective complaint score was obtained for each of leg dullness, leg pain, and whole-body fatigue. Each score was recorded at two-minute intervals, and expressed as a level numbered 1–10, with 1 being the lowest level and 10 the highest.

Analysis
The leg-swelling level was derived from the rate of change in impedance according to the following formula:

\[ \Delta Z% = \frac{(Z_0 - Z_t)}{Z_0} \times 100 \]

where \( \Delta Z% \) is the rate of change in impedance at time \( t \), \( Z_0 \) and \( Z_t \) is the measured impedance at time 0 and \( t \), respectively. According to the results of our previous study, the \( \Delta Z% \) is theoretically about four times larger than the rate of the leg volume change.

The exercise speed was tested by one-way analysis of variance (ANOVA) for the exercise periods. \( \Delta Z% \), leg dullness, leg pain and whole body fatigue were tested by two-way ANOVA and Tukey’s multiple comparison with the exercise and subject taken as two factors. The significant level was assumed to be 5%.

Results
Figure 1 shows the means and SD of the exercise speed at each exercise period. The exercise speed was almost constant throughout the five cycles of exercise. None of the exercise speeds depended significantly on the time course.

The time course of the leg swelling according to the type of exercise is shown in Figure 2. Vertical lines indicate the periods of exercise. Under all exercises, \( \Delta Z% \) increased with time, indicating a concurrent increase in leg swelling. Knee-bending showed the strongest swell-preventing effect, and heel-raising the weakest. Both the effect of walking and foot-stepping were at the middle level. The means and SD of the \( \Delta Z% \) were 1.3 ± 4.5% for the knee-bending, 2.4 ± 2.8% for the foot-stepping, 1.6 ± 3.4% for the walking, and 3.0 ± 3.4% for the heel-raising. The difference in \( \Delta Z% \) among the types of exercise was significant. \( \Delta Z% \) for the knee-bending was significantly different than that for the heel-raising, by multiple comparison.

In the case of knee-bending, the temporal decrease in leg volume after just a single minute of exercise was remarkable. The temporal decrease in \( \Delta Z% \) were 0.19 ± 1.28% for the knee-bending, 0.28 ± 1.50% for the foot-stepping, -0.91 ± 2.35% for the walking and -0.61 ± 1.60% for the heel-raising. The difference in temporal decrease among the exercise types was significant (F=10.23,
df=3,208, p<0.0001). In multiple comparisons, temporal ΔZ% decrease was significantly different in all combinations of types of exercise, except in the pair of heel-raising and foot-stepping, and the pair of knee-bending and walking.

The time course of the subjective complaint scores is shown in Figure 3. The subjective complaints were strengthened over time under all the conditions of exercise. The scores for leg-dullness and leg-pain were higher than that for whole-body fatigue, but recovered to their former level within 4–6 min after exercise.

The leg-dullness score was highest under heel-raising, and at approximately the same level in the other exercises. While the leg-pain score showed a similar tendency, its margin of difference between the heel-raising and other exercises was smaller than the leg-dullness score. Statistically, however, there was no significant difference among exercise types in either leg dullness (F=0.26, df=3,36, P=0.86), leg pain (F=1.08, df=3,36, P=0.37), or whole-body...
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Discussion

According to the results of this study, lower leg volume increased under all conditions of exercise, contrary to Stick’s result of the volume decrease during 18 min of continuous cycling exercise⁶. This can be explained by the exercise interval. In our experiment, the exercise was continued only one minute, and was repeatedly followed by nine minutes of quiet standing. The leg swelling during quiet standing was considered to be higher than the swell-preventing effect of the exercise. The means of the change rate of impedance at 30 min were 1.3–3.0% by our results. The exercise suppressed the leg swelling as the change rate of impedance at 30 min was 6.9 % under continuous quiet standing according to our previous result¹².

The change rate of the impedance for one hour under knee-bending, foot-stepping, walking and heel-raising were 2.2%, 4.0%, 4.6%, and 6.3%, respectively. The swell-preventing effect was lowest under heel-raising, although this exercise was considered to work the calf muscle pump well. This result agrees with the previous report that the leg volume increased in about half the number of subjects under the condition of 20 min of heel raising⁹. Stick et al. reported that the thigh volume increased during 10 min of cycle ergometer exercise⁷. A fluid shift caused by an increase in osmolality during hard muscle exercise⁷ is mentioned as a probable cause of the thigh volume increase⁷. The same mechanism may account for the relatively high volume increase under heel-raising. Because heel-raising used only a limited part of the leg, it allowed the swell-preventing effect of the calf muscle pump to be negated by increased osmolality. The swell-preventing effect was highest under knee-bending, which uses the thigh muscle more than the other exercises. It is reasonable to suppose that the muscle pump of the whole leg is more effective than that of the calf alone. The exercise using the thigh and the calf muscle together at a moderate level is effective for preventing lower-leg swelling. But overexercising only the calf muscle potentially increases the lower-leg swelling.

The temporary volume decrease just after exercise was observed under knee-bending and walking. However, in both cases, the previous value returned after two minutes standing, as shown in Figure 2. The swell-preventing effect remained at the same level during the full hour under walking and foot-stepping, although the temporary volume decrease was not observed under foot-stepping. The temporary volume decrease did not reflect the swell-preventing effect for one hour completely. The characteristics of the plethysmographic measurements are concerned with this difference between the temporary volume decrease and long-term swell-preventing effect. The plethysmography can only detect changes in the gross amount of the leg volume, including the intravascular as well as the extravascular component. When the venous pressure increases, the extravascular volume continues to increase, while the intravascular volume stabilizes within a few minutes after a venous congestion¹⁴. The temporary decrease of the impedance changing rate just after exercise is considered to reflect the lightening of the venous congestion by the muscular contraction in this study. A rapid filling of the vessels occurs subsequently during nine minutes standing. More experiments will be required to show whether the venous dilation actually occurs after exercise. In any case, it is clear that the swell-preventing effect of inserted exercise during long standing cannot be

![Fig. 3. Changes in the leg dullness, the leg pain, the whole body fatigue (mean and SE) during one hour standing](image-url)
concluded only from the results before and after a single exercise period using plethysmographic measurement.

This study was observed under free speed exercise because the speed was considered to be autoregulated according to the subjective complaints. The speeds of all exercises, however, did not change over time. One reason for the constant speed may be muscle fatigue. Although each muscle movement was effective for the subjective complaints, subjects seemed not to exercise more quickly than the speed which made them feel muscle fatigue.

The subjective complaints of leg dullness and leg pain were stronger under heel-raising than under the other conditions. This result is considered to be influenced by the load of using the calf muscle to raise the whole body weight. Previously, we have mentioned that mental stress might be dominant in monotonous standing jobs\(^{12}\). The complaints under heel-raising and foot-stepping were improved just after exercise, although the leg swelling was not relieved. This result may suggest an alleviation of mental stress during quiet standing. The dissociated relationship between the subjective complaints and leg swelling is corroborated in a study comparing leg swelling under conditions of erect standing, sitting in an ordinary chair, and sitting in a modified “buttock” chair\(^{15}\). In order to clarify the cause of the subjective complaints, other experiments will need to be performed, possibly including electromyography or investigations of biochemical reactions in muscle. But it is certain that leg swelling is not always predominant in the subjective complaints. And regardless of the cause of the disparity between subjective complaints and leg swelling, inserted exercise can effectively reduce the subjective complaints. This is made clear by the improved subjective complaint score following exercise.

To prevent lower-leg swelling, the most important measure is to avoid long-term standing. This measure must be examined as a first-choice improvement of the work method. Intermittent exercise is the second choice, in cases where workers cannot avoid motionless work. When recommending any exercise, the degree of effectiveness seems dependent on the use of the thigh muscle, as in the exercise of knee-bending. There was no clear difference between the walking and foot-stepping, but these exercises can be considered a reasonable approach when the working process does not permit a dynamic movement like knee-bending. For the latter solution, time and free exercise space will have to be secured.

References