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Dynamic leg volume changes when sitting in a locked and free-floating tilt office chair

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It is well established that prolonged sitting may lead to swelling of the lower extremities. However, activation of the vein pump system by repeated walking breaks or dynamic tiltable foot-rests have been shown to reduce foot and leg oedema. Some office chairs incorporate tilt-mechanisms facilitating movements of the body from the feet up. The present study was undertaken to establish whether a beneficial effect on the transcapillary fluid balance of the legs by enabling such mechanisms could be documented. An office chair where the tilt mechanism could be locked or open (HÅG Credo 3500) was used for the study. The seat position and seat activity level was recorded by a transducer-system developed for the study. Calf volume and calf muscle pump activity was detected by mercury strain gauge plethysmography.

In the locked position there was a steady increase in volume of mean 1.2 % (range 0.8 - 1.8) for all subjects in the 30 min. study period. On the other hand, for all subjects there was a decrease in calf volume (mean –0.7 %, range –0.1 - -1.2, p=0.008) when the tilt-mechanism was open (30 min. period), irrespective of what study period came first. The study showed that upward seat deflection was not associated with concomitant venous obstruction, since such obstruction was detected in less than 2 % of the time period with more than 50 % of maximal upward deflection. A locked seat mechanism does not prevent activation of the vein pump mechanism, but the study indicates that office chairs that permit variation in seat angle *per se* stimulate movements of the leg. This, in turn, activates vein pumps and counteracts local oedema formation in seated working postures.

1. Introduction

An increasing number of jobs are associated with sitting postures (Peters 76, Östberg 77, Winkel 81). However, prolonged sitting may lead to swelling of the lower extremities, especially in constrained postures (Gauer and Thron 1965, Pottier *et al.* 1969, Winkel 1981, Stranden *et al.* 1983, Paul 1995, Stranden and Kroese 1998). Oedema results from increased net transcapillary filtration, exceeding removal of fluids by the lymphatics. The dominant factor promoting oedema is increased capillary hydrostatic pressure, caused by increased venous pressure. The vein pressure of the feet in a horizontal position is approximately

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5 mmHg, increasing to 70-80 mmHg in a upright position. At passive sitting, the pressure is in the order of 45 - 60 mmHg, determined by the height of the blood column from the feet to the heart. When walking, the vein pressure normally decreases to 25 - 30 mmHg, caused by vein pump mechanisms in the lower extremities (Stranden *et al.* 1986, Gardner and Fox 1989).

Based on this knowledge, Winkel (1981) and Winkel and Jørgensen (1986) suggested inclusion of short walking breaks in office work to reduce the amount of leg/foot oedema. Significant reduction in swelling of the legs has also been documented, when using a specially designed dynamic foot-rest in constrained factory workstations. This was based on a pivot that allowed "treadle" action to be performed by the operator (Stranden *et al.* 1983, Stranden and Kroese 1998).

Some office chairs incorporate a tilting-mechanism that combines the movement of the seat and backrest in such a way that the front of the seat is lifted upwards when one leans on the backrest. Among the rationales for such a mechanism is that they facilitate movements of the whole body from the feet up (dynamic sitting pattern). Consequently, one may assume that if the muscle activity of the lower extremities is stimulated, this would enhance venous pumping, thereby reducing the distal vein hydrostatic pressure. Critics of such a tilt mechanism argue that a seat deflection upwards when leaning on the backrest results in increased pressure at the back of thigh and thus causing venous obstruction and increased transcapillary filtration.

The current study was undertaken to investigate whether the dynamic sitting pattern of office chairs with free-floating tilt mechanism had significant beneficial effect on transcapillary fluid balance in healthy controls.

1.1. *Physiological considerations*

1.1.1. *Lower extremity vein pump system:* The most important oedema limiting mechanism of the lower extremities is the venous pumping system, which, when activated, reduces distal venous pressure at upright or seated position. In relation to function, the venous pumping system may be divided into three portions with different working mechanisms (Gardner and Fox 1989) (figure 1):

(1) the muscle pumps;
(2) the distal calf ("piston") pump; and
(3) the foot pump

1.1.2. *The muscle pumps:* The pump unit consists of muscles ensheathed by a common fascia, which is drained by a set of densely-valved intra- and intermuscular veins. These in turn empty into more sparsely valved proximal veins (Arnoldi 1989). The leg contains four muscular compartments: The anterior, lateral, deep posterior and superficial posterior, all drained by their respective veins.

Muscle contraction is the main activator of muscle pumps (Ashton 1975), but passive stretching may also raise intramuscular pressure and promote pumping. Baumann *et al.* (1979) recorded pressures of >100 mmHg in the tibial anterior muscle during contraction and 35 mmHg on passive stretching.

Contraction of the calf muscles initiates a rise in pressure in all veins of the lower limb. The increase is most pronounced within muscle veins, three times higher than in superficial veins. During muscle contraction (systole) the greatly increased pressure difference between deep calf veins and the popliteal vein causes rapid flush of blood from the calf to the thigh (figure 1). Retrograde flow is prevented by competent venous valves. On subsequent muscle

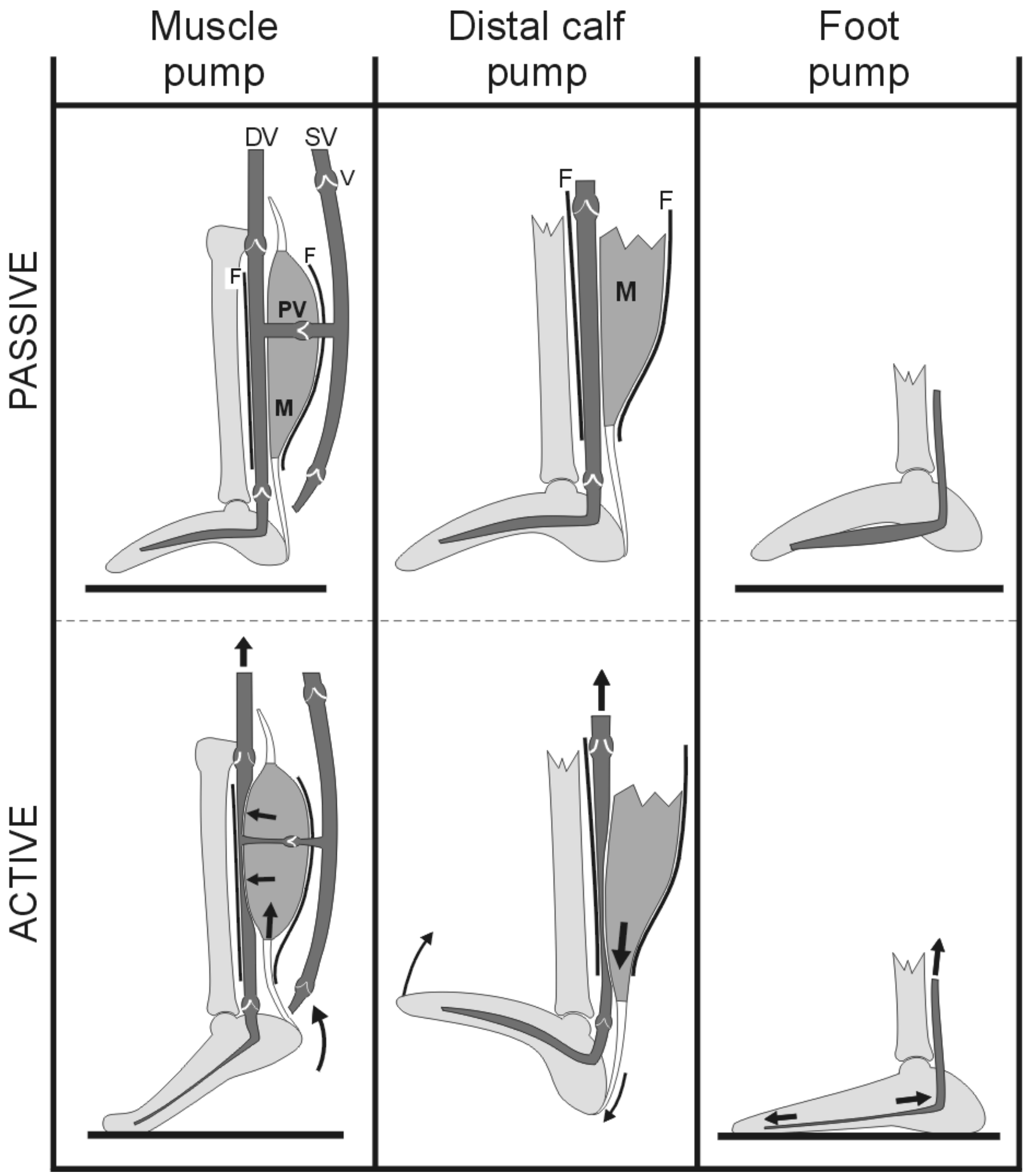

Figure 1. Schematic illustration of the venous pump systems of the foot and calf in relaxed and active state. The *muscle pump* unit consists of muscles (M) ensheathed by a common fascia (F) and veins within the same compartment. Contraction of the calf muscles (muscle systole), as in plantar flexion of the ankle joint during walking (below), expels blood into the proximal collecting vein. During relaxation (muscle diastole, above) the blood is drained from the superficial veins (SV) into the deep veins (DV) in addition to the arterial inflow, making the pump ready for the subsequent ejection. V: venous valve. The *distal calf pump* is indicated in the middle. On dorsiflexion of the ankle (passive or active), the bulk of the calf muscle (M) descends within the fascial sheath (F), and expells blood in the distal veins like a piston. The *foot vein pump* is illustrated to the right. The plantar veins are connected like a bow-string from the base of the fourth metatarsal in front to the medial malleolus. On weight-bearing the tarso-metatarsal joints are extended and the tarsal arch is flattened. Thus the veins are stretched, causing them to eject their content of blood.

relaxation (diastole) venous pressure falls below the pressure at rest. The fall is greatest in the deep veins, less in the superficial veins and insignificant in the popliteal vein. In this phase perforator veins allow flow from the superficial to the deep veins, whereas competent valves prevent backflow from the popliteal to the deep calf veins.

The calf pump is probably the most important muscle pump. However, also the thigh pumps (quadriceps muscle pump, sartorial muscle pump, the pump of the hamstring muscles) and the popliteal vein pump (Hach 1976) play a part in the centrally directed propulsion of blood.

1.1.3. *The distal calf ("piston") pump:* In contrast to conventional descriptions, there are two pumping systems in the calf, a proximal and a distal (Gardner and Fox 1989). The distal one is activated on dorsiflexion of the ankle (figure 1), when the calf muscles are stretched and their distal part descends within the fascial sheath. This movement acts like a piston which expels venous blood in proximal direction. The pump mechanism has been documented by ultrasound Doppler measurement of venous blood flow (Gardner and Fox 1989), and is supported by compartment pressure measurements (Gershuni *et al.* 1984).

1.1.4. *The foot pump:* The significance of a pumping system within the foot has often been overlooked, although first postulated by Le Dentu in 1867. Gardner and Fox (1983) used video-phlebographic technique and ultrasound Doppler measurement to demonstrate a potent pump mechanism in the deep plantar veins. The pumping mechanism has been explained as follows. The plantar veins are connected like a bow-string between the base of the fourth metatarsal and the medial malleolus. On weight-bearing, the tarso-metatarsal joints are extended and the tarsal arch is flattened. Thus the veins are stretched, causing them to eject their content of blood (figure 1). The pump is also activated on weight-bearing of the forefoot alone, when the foot is acting like a lever (Gardner and Fox 1989) (figure 1, left portion).

1.1.5. *The pumps acting together:* During normal walking the three vein-pumping systems are synchronised to form a complete network of serial and parallel pumps aiding the return of blood towards the heart. Even moderate muscular movements of the legs in seated position may activate the pumping mechanism, significantly reducing distal mean vein pressure (Stranden 1981, Stranden *et al.* 1983, Stranden and Kroese 1998)

2. Methods

2.1. *Participants*

Eight healthy control subjects (3 females, 5 males) were studied. The mean age was 35 years (range 21 - 48). None had clinical signs or medical history indicating arterial or venous disease.

2.2. *Chair*

An office chair with a centre tilt mechanism and a fixed angle between the seat and the back was used for the study (HÅG Credo 3500, HÅG a.s.a. Oslo, Norway). The linkage between the seat and the back results in an upwards deflection of the seat front when the chair is tilted backwards and the seat front is moved downwards when the chair is tilted forwards.

The chair had adjustable seat height and seat depth as well as adjustable supporting point of the backrest. The backrest also had an individual pivot action. Resilient means are attached on either side of the pivot point of the seat. These could be adjusted to fit the users preference and ensure balanced sitting.

This chair was chosen because of its wide spread use and because the tilt mechanism was easily locked/unlocked with a lever. When the tilt mechanism is open the movement that occurs is described as "free-floating tilt"

2.3. *Seat angle/activity detection*

For continuous recording of seat angle and seat activity, a transducer system was developed (figure 2). The transducer detects the position of the seat/backrest relative to the fixed, vertical axis of the chair (90° to the floor). The detector element is a potentiometer supplied with a ± voltage. The detector output voltage is balanced at zero when the chair is neutral, positive when the seat front is deflecting upwards, negative when deflecting downwards. The signal was fed via an analogous/digital converter (DT2801, Data Translation, Inc., Marlboro, MA, USA) to a PC.

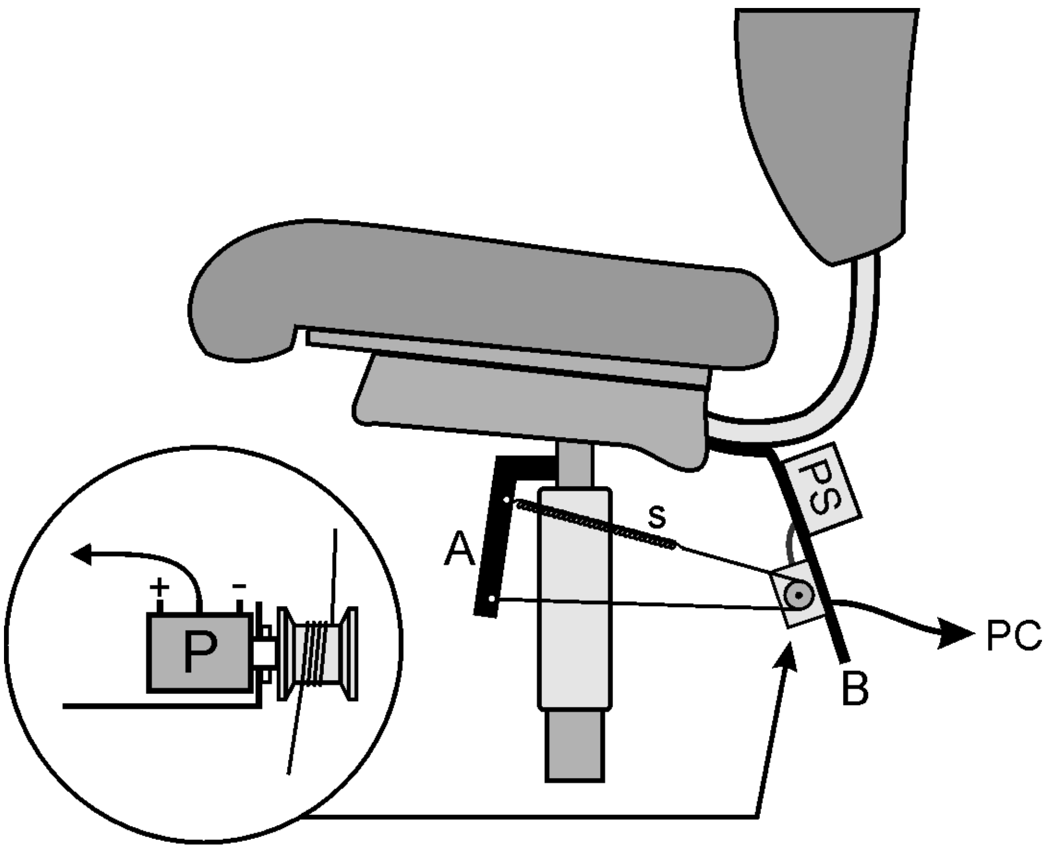

Figure 2. The transducer system developed (E.S.) for the detection of seat angle/activity. The iron bar A is fixed to the vertical chair stem, and B follows the movements of the seat/backrest. The wire/spring (s) attachment to a potentiometer (P) ensures a variable output voltage, representing seat deflection. The potentiometer is supplied with a ± voltage (PS). The detector output voltage is balanced at zero when the chair is neutral, positive when the seat front is deflecting upwards, negative when deflecting downwards.

2.4. *Measurement of leg volume changes*

Variation in calf volume was measured by strain-gauge plethysmography (Whitney 1953), using a double mercury in silastic strain-gauge around the greatest circumference of the calf. Indentation of the skin underneath the strain-gauges was prevented by 10-15 underlying matches. The plethysmograph ("Strain Gauge Plethysmograph", developed by E.S.) was equipped with electrical calibration (Brakkee and Vendrik 1966) permitting repeated calibrations between measurements. The electrical calibration was compared with mechanical stretching of the strain-gauges by use of a micrometer, and an exact linear relationship was found between extension of the gauges and the recorded volume change.

2.5. *Recording of data*

Perisoft software (Perimed AB, Järfälla, Sweden, www.perimed.se) was used for recording and analysis of data. The recorded data were: 1. Variation in calf volume, and 2. Seat angle/activity. The software allowed changes in timescale (x-axis) and signal amplification (y-axis) to fascilitate the analyses. The software included Fourier analysis as described by Press *et al.* (1997).

2.6. *Experimental design*

Following connection to the measurement devices, the chair was adjusted individually, and it was also ensured that the thigh was in a horizontal position with 90° flexion of the knee joint. A fixed angle of the knee in the resting condition before and after measurement was important, because the cross section of the passive calf muscles is dependent upon the muscle extension. The calf volume level before and after each session was determined following a 2-min.-period with the legs at rest, to ensure blood-filled veins. Calibration signals (1.0 % calf volume increase) were included at the beginning and end of each recording.

The recordings were performed under the following two conditions:

1. Tilt-mechanism in locked position for 30 minutes (locked phase). The person was free to move, but the chair did not follow the movement.

2. Tilt-mechanism open, allowing the free-floating tilt of the chair for 30 minutes (free-floating phase).

In half of the studies the procedure was carried out in reversed order, to establish whether the procedure itself affected the measurements. The study leg was chosen at random.

During the two phases, the study persons were occupied with standard seated office tasks, manipulating documents on the desk and performing computer procedures. Before measurements, they were familiarized with the chair in a test period. They were instructed to choose their own preferred sitting pattern and leg activity level

2.7. *Statistics*

With the limited number of persons included, normal distribution was not expected, and non-parametric tests were chosen. For comparison between the investigation phases, Wilcoxon signed rank sum test (two-tailed) for paired observations were used (program Graphpad Instat 3.0, Graphpad Software, Inc., San Diego, CA, USA, www.graphpad.com). Differences were considered significant when p-values were less than 0.05.

3. Results

A typical recording of leg volume change and seat activity during the two study phases is shown in figure 3. The locked phase is shown to the left. Relatively little muscle movements are recorded, as indicated by the steadily increasing volume curve with minor deflections. To the right the tilt-mechanism is open, allowing free-floating tilt. A clearly more active sitting pattern follows, indicated by the volume curve and the transducer signal. Secondly, a slight downward volume slope by time may be drawn in this portion of the measurement.

In figure 4 the volume changes for all extremities in the two phases are depicted, expressed as volume change per study period of 30 min. For all there was a volume increase in the locked phase (mean 1.2 %/30 min., range 0.8 - 1.8), and varying degree of volume reduction in the free-floating phase (mean –0.7 %/30 min., range –0.1 - -1.2). The difference between the phases was statistically significant (p=0.008). In two subjects the volume recording during free-floating was two-phasic, consisting of both volume decrease and increase. For these, the net change in volume between start and end of the 30 min. period was used, making these results less reliable. No obvious difference in movement pattern between these two and the others was detected.

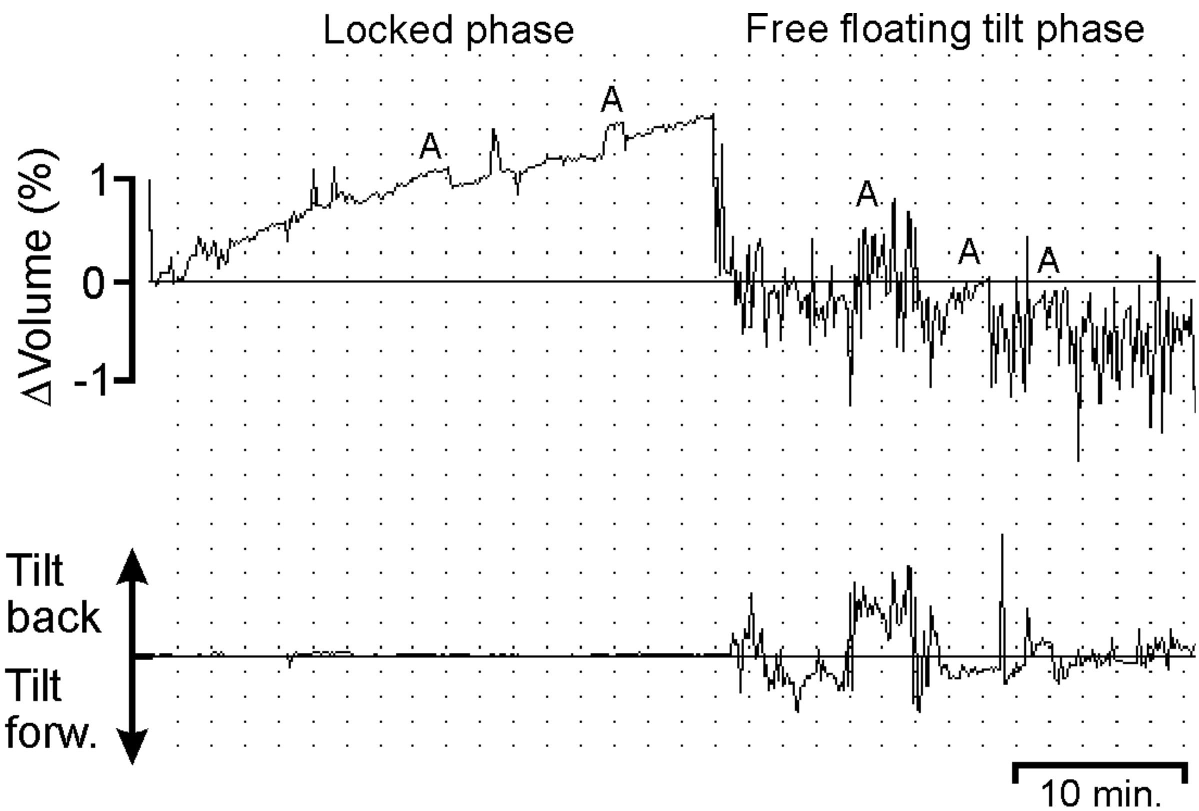

Figure 3. Typical recording of calf volume changes (upper curve) and chair seat activity as detected with the transducer described in figure 2 (lower curve). The left portion of the recording represents the study phase with the centre tilt mechanism locked; to the right the seat is made tiltable by enabling the centre tilt mechanism. Each period has a duration of 30 minutes. The transient changes in volume, indicated by “A”, represent changes in the cross-section of the muscles underneath the strain gauges taking place when varying the degree of flexion of the knee joint. The changes do not represent variation in venous- or interstitial volumes.

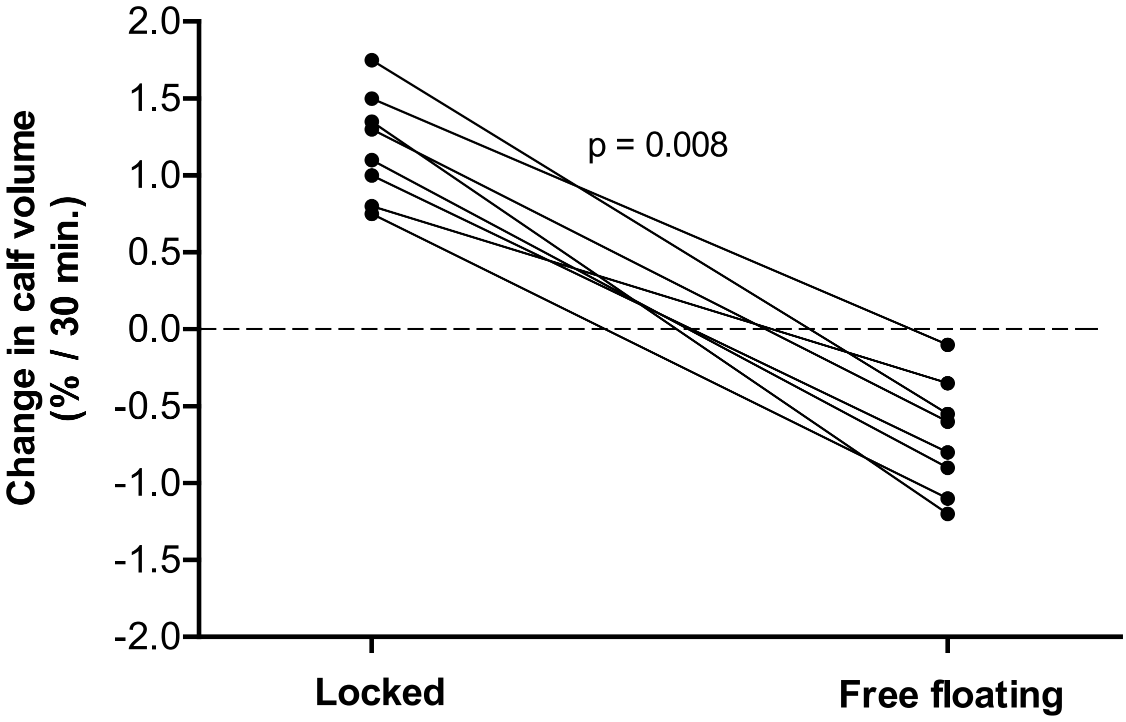

Figure 4. Calculated volume changes (%) per 30 min. with the seat locked (volume increase) and open (volume reduction) for the eight measurements. There was a significant difference between the two phases.

There was no significant difference between the recordings that started with the seat locked and those that started with the free float phase.

Figure 5 represents a 5-min. selection from the free-floating phase in figure 3. The volume curve indicates volume reductions by activating the vein pumps at even moderate seat deflections (left portion of the curve). Following each deflection, the volume increased steadily during the next 30 s to approach the pre-deflection level, as the veins are filled from the arterial side. Increasing the level of seat deflection (right portion of the curve) does not imply corresponding increase in calf volume deflections. This finding is even more prominent in figure 6, showing volume changes of the same order of magnitude as those in figure 5, at minimal seat deflections. Similar recordings were also found for the other subjects.

As the study did not show unambiguous correlation between vein function and seat activity, the recordings were reanalysed, focusing on venous pumping, irrespective of seat movements. In this analysis "significant" venous pumping was recorded, defined as leg activity causing volume reduction of more than 0.5 %. The result from this analysis is shown in figure 7. There was an increase in the number of "significant" vein pump events when the chair had a free-floating tilt, from 50 events per 30 min. in the locked phase (range 23 - 82) to approximately 200 per 30 min. in the tiltable phase (mean 191, range 122 - 254) ($p=0.008$).

To establish a possible relationship between upward seat deflection and venous obstruction, the periods with more than 50 % upward deflection was examined. All subjects together, the sum of these periods amounted to about 85 min. (range 3 - 17 min.) of a total free-floating study time of 240 min. In these periods, only four incidences for a total of 1.5 min., with a slight volume increase indicating venous obstruction was detected.

Figure 5. A 5-min. selection from the free-floating tilt phase in figure 3, indicating moderate seat deflection in the left portion and more extensive seat movements to the right. Note that the venous pumping, as judged from the downward slopes (ejection of venous blood) not necessarily becomes larger when the magnitude of the seat movements are intensified.

Figure 6. A 5-min. selection from the free-floating tilt phase in figure 3, showing venous ejections with similar magnitude as in figure 5, at minimal seat deflections. The ejections are predominantly based on static muscular activity.

The great variation in movement pattern for the subjects is indicated in figure 8, a Fourier analysis of the free-floating tilt- and locked seat phases. Major movement components are in the frequency domain below 10 cycles/min., but with large interindividual differences. The frequency plots from the tilt phases were subjectively graded in a scale of 1 - 5, according to amplitude and frequency distribution. There was no correlation between these data and the

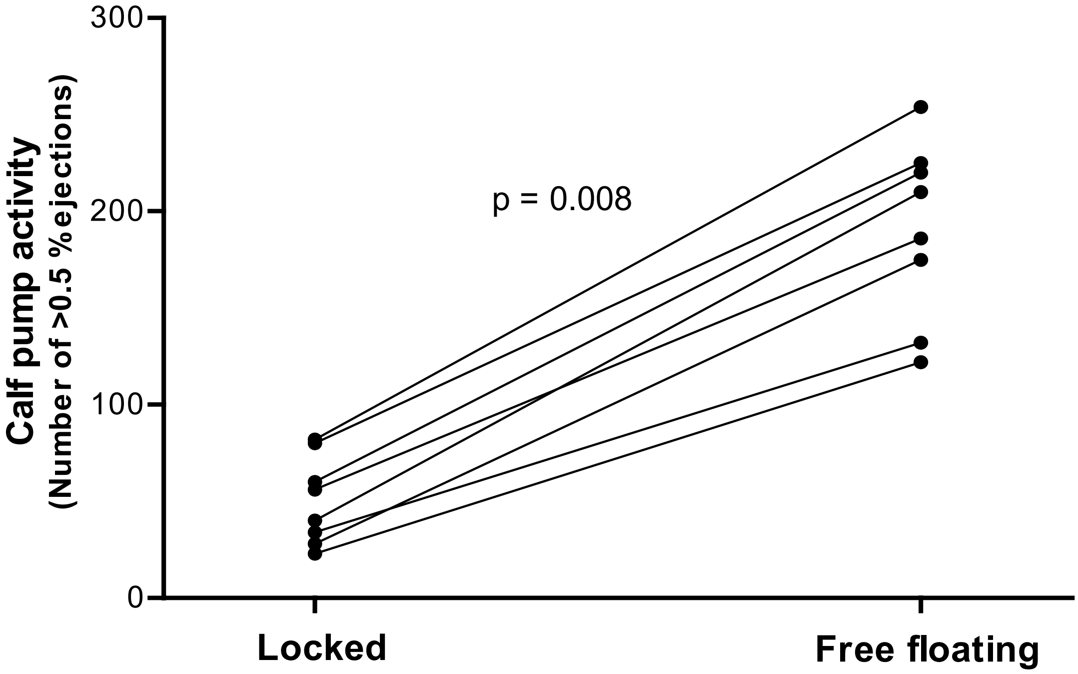

Figure 7. Number of "significant" venous pump manoeuvres in the locked and free-floating tilt phases, defined as leg activity causing volume reductions of more than 0.5 %. The increase in muscular activity level was statistically significant.

level of calf volume reduction. In fact, the two recordings with the highest score were among the three with the lowest volume reduction in the active phase
(mean –0.3 %). Furthermore, for the two subjects with the lowest score the volume reduction was above the mean value for all subjects (mean –0.7 %).

4. Discussion

The most important finding in this study was that use of a seat attachment mechanism allowing free-floating tilt movements stimulates sitting patterns that activate vein pumps of the leg. Previous studies (Stranden *et al.* 1983, Stranden and Kroese 1998) showed that volume reduction during activation of the vein pumps occur in parallel with reduction in vein pressure. In periods with a large number of "significant" vein pump manoeuvres the mean venous pressure is presumably reduced. This reduces capillary pressure, which is the most important component for altering transcapillary fluid balance, thereby reducing net transcapillary filtration.

Another finding was that functional vein pump manoeuvres did not presuppose variation in seat angle, even in the free-floating tilt phase. Hence, at least part of the physiological venous pumping is caused by static muscle activity. This type of muscular movements is present in both study phases. There is no reason to believe that locked seat position *per se* prevents these static contractions. As the analyses nevertheless showed three times higher frequency of "significant" pumping manoeuvres in the tilt phase, an interpretation may be that this seat mechanism and combination of fixed angle between seat and backrest *stimulates* movements, since the working tasks in the two phases were identical.

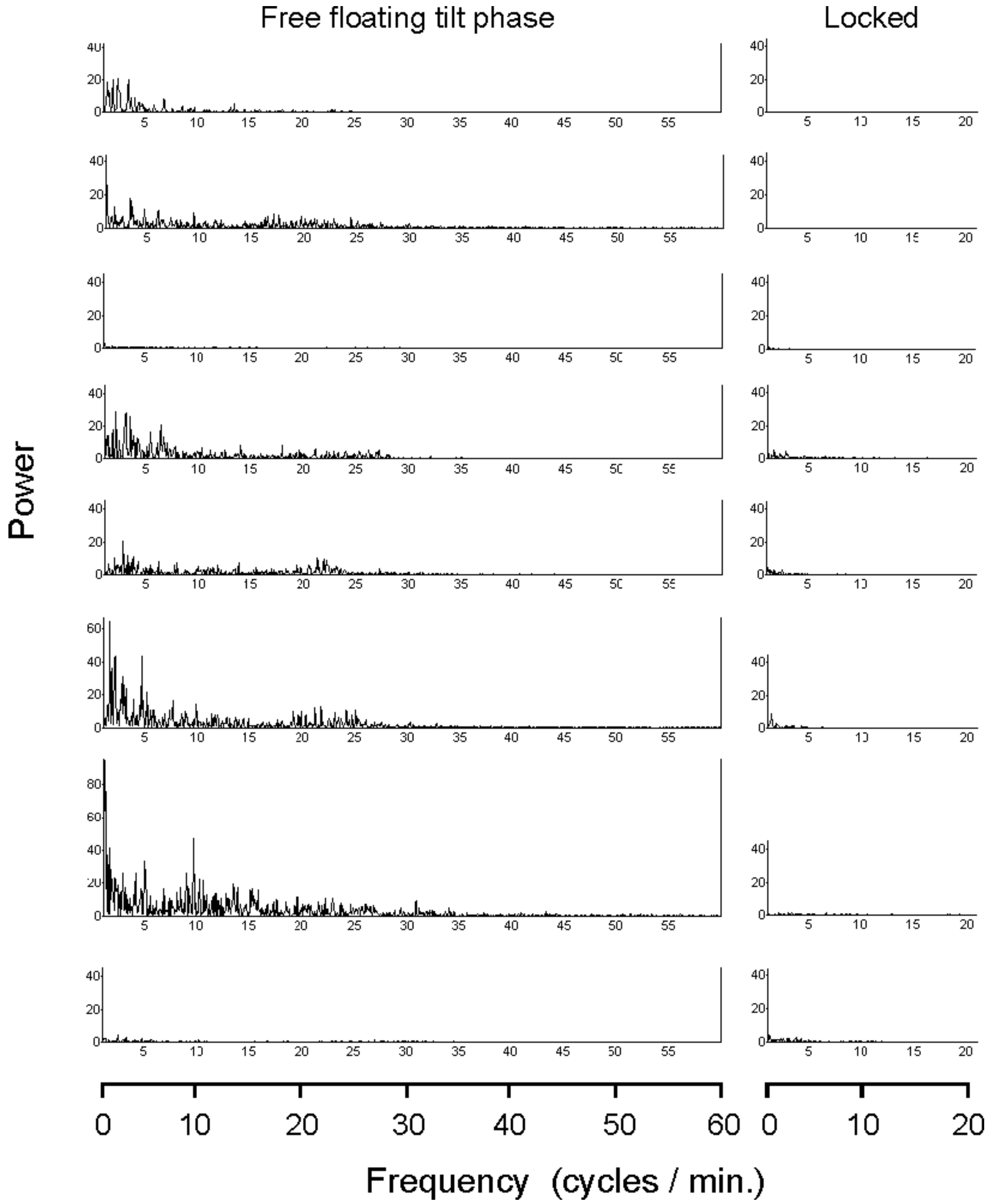

Figure 8. Fourier frequency analysis of the two study phases for each leg studied. The diagrams for the locked phase are truncated because there was no detected activity above the frequency domain 0-20 cycles/min. A great variation in movement pattern between the individuals is evident from the free-floating tilt phase.

The present seat mechanism that incorporates movements like those of a rocking chair is suitable for activating the vein muscle pumps. The plantar flexion of the feet and contraction of the calf muscles taking place when leaning back effectively initiates venous pumping (Stranden *et al.* 1983). The degree of calf volume reduction did not depend on the extent of leg movements, as evaluated by the frequency analysis. The interpretation may be that the venous pumping mechanisms are very potent and effective, and venous drainage causing reduction in venous pressure occurs even at moderate, but frequent movements. This is in line with a previous study where we found that a single plantar flexion was as effective in reducing venous pressure as a series of pumping manoeuvres (Stranden *et al.* 1983). Another explanation lies in interindividual differences between the subjects studied.

We have previously shown that constrained working postures often lead to passive sitting and oedema formation in foot and leg (Stranden *et al.* 1983). The fluid accumulation in the tissue resulted in significant increase in tissue hydrostatic pressure, which may partly explain the discomfort reported (paresthesia, numbness, pain). By introducing specially built dynamic footrests allowing "treadle" action of the feet against a weak counterpressure, the discomfort and swellings were significantly reduced (Stranden *et al.* 1983, Stranden and Kroese 1998). The present study confirms the previous findings, demonstrating the potential of the venous pumps in restoring normal transcapillary fluid balance in a sitting posture.

The volume changes in the current study (both increase and reduction) are somewhat larger than those associated with the dynamic foot-rest. This may be attributed both difference in study population, and the possibility that the freely movable sitting posture when using free-floating chair seat is more effective regarding vein pump mechanisms. Furthermore, the present work tasks were more varied, enabling more freely movement of the body than in the constrained industry workplace (Stranden *et al.* 1983).

The study did not support the finding of Pottier *et al.* (1969) that upward seat deflection is associated with venous obstruction in the distal thigh. In less than 2 % of the time period with significant (>50 %) upward slope there was a slight volume increase, indicating venous obstruction. A considerable pressure at distal thigh, where the deep vein runs deep within the Hunter's canal, is required to compress the vein, probably far beyond discomfort. Furthermore, the great saphenous vein (superficial vein), which has a great capacity for venous drainage, is located antero-medially and is not subject to compression in seated posture. The only region where compression is likely to occur is in the popliteal area. As the seat depth of study chair is adjustable, the depth of the seat was checked, and when neccessay adjusted, to avoid compression at the knee level in those subjects with a short thigh length.

Furthermore, the flexion of the knee joint during upward seat deflection does not represent a likely cause for venous compression. This is evident from earlier studies on "Balans" chairs, where venous pressure recordings at very much larger flexion did not indicate any venous obstruction at all (Stranden 1981). The most extreme sitting posture was applied at "Balans Skulptur", where flexion was about 160 - 170°; still with no venous obstruction affecting venous pressure profiles.

The volume recordings during the present 30 min. periods may not be extrapolated to cover a total working day. Usually the working period is interrupted by breaks and walking to different tasks, which has been shown to reduce the oedema development (Winkel and Jørgensen 1986).

In conclusion, the present study indicates that office chairs which permit variation in seat angle when the upper body moves *per se* stimulate movements of the leg. Leg movements are beneficial because they activate the venous pumping mechanisms, thus counteracting local oedema formation in leg and feet, and reduce discomfort in seated working postures.

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