The relationship of foot and ankle movements to venous return in the lower limb

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We have studied the relationship between movements of the foot and ankle and venous blood flow from the lower limb using colourflow Duplex ultrasound to determine the optimum type of exercise for promoting venous return. Studies of both active and passive movements were carried out on 40 limbs in 20 subjects (18 men; 2 women), with a median age of 27 years (20 to 54). We assessed ankle dorsiflexion and plantar flexion, subtalar inversion and eversion, and a combination of all movements.

There was no difference in venous flow when comparing opposite limbs in a single subject (p > 0.5), but active exercises produced higher peak and mean velocities of blood flow than passive ones. The active combined movement produced the highest velocities with an increase of 38% in mean and of 58% in peak flow velocities, which were significantly greater than the peak and mean flow rates produced by passive movements. The active combined exercise would therefore be the most effective in eliminating stasis and could contribute to the prevention of deep-vein thrombosis.


There has been much debate about the most effective method of prophylaxis for deep-vein thrombosis (DVT), especially since the risk of fatal pulmonary embolism has been established to be significantly lower than previously accepted.1,2 Virchow’s triad of the factors involved in venous thrombosis is hypercoagulability, stasis and injury to the intima. Chemical methods of prophylaxis are primarily directed towards decreasing coagulability; mechanical methods attempt to decrease stasis.

Chemical prophylaxis is associated with a risk of morbidity and mortality, which many surgeons believe to be unacceptable, and therefore mechanical methods of prophylaxis are now being used more widely.3-5 It has long been recognised that regional anaesthesia,6 surgical technique7 and early postoperative mobilisation8,9 can reduce the incidence of thromboembolism. Other methods such as antiembolism stockings10 electrical stimulation of the calf11 and pump systems12-14 promote venous return and have been recommended. The efficacy of antiembolism stockings has recently been questioned15 and other systems may be expensive, bulky and often poorly tolerated by the patient.

Our aim was to investigate the relationship between movements of the foot and ankle and venous return from the lower limb. We have compared movements in separate planes and quantified the difference between active and passive movement. The results were compared with popular and effective mechanical methods of prophylaxis. This simple and inexpensive method of eliminating stasis and promoting venous return, which could be incorporated into a general rehabilitation programme, may be of benefit in reducing the risk of venous thrombosis.

Subjects and Methods

We constructed a simple apparatus which allowed the study of venous return from the lower limb in relation to active and passive movement of the foot and ankle and eliminated unwanted movements (Fig. 1). It allowed the isolation of individual axes of movement so that ankle ‘flexion’ dorsiflexion and plantar flexion) and ‘rotation’ (subtalar inversion and eversion) could be studied both separately and in combination. Complete studies were carried out on 20 healthy volunteers. They had no history of or risk factors for DVT and no previous operations on the lower limb. There were 18 men and two women with a median age of 27 years (20 to 54). To eliminate the potential for interobserver variation, all of the measurements were carried out by one experienced senior vascular research technologist.

At the beginning of each study, the subject lay supine on an examination couch with the leg in the apparatus. The thigh was at an angle of approximately 30° with the calf...
horizontal. The subject rested for five minutes before peak and mean velocity measurements were taken. A colourflow Duplex ultrasound image of the full width of the common femoral vein was obtained using a 5 MHz linear array ultrasound transducer (Advance Technology Laboratories, Bothell, USA) at an angle of between 55° and 60° to the wall of the lumen. This was connected to an Ultramark-9 High Definition Imaging scanner (Advance Technology Laboratories). We obtained an accurate real-time spectral waveform of the blood velocity in the femoral vein using an angle-correction facility to compensate for minor variations in the angle of the transducer. Screen cursors were used to measure peak velocities of blood flow at three time points. The spectral trace was used to calculate the mean blood flow over each five-second interval and this measurement was also repeated at three time points.

Three types of exercise were then carried out, both passively and actively, and the mean and peak velocities
were again repeated three times during each movement. The subjects were rested between exercises until the blood flow had returned to the resting levels. The recordings at the beginning of each exercise were rejected since higher blood velocities were initially obtained due to the effect of venous blood pooling in the calf muscles of the leg before exercising. When the equilibrium between arterial filling and venous return had been established the velocity readings were found to be reproducible, allowing measurements to be made.

**Statistical analysis.** All data were log-transformed to give a normal distribution and thus facilitate parametric statistical testing. We determined a two-way analysis of variance with repeated measures of two factors for comparison between peak and mean velocities of blood flow in both limbs of each subject, before and during exercise.

Analysis of variance (ANOVA) was then determined, with repeated measures on one factor, to allow specific comparisons between the results of different exercises. All data were then anti-Log-transformed to give estimated geometrical means and 95% confidence intervals.

**Results**

In individual subjects, there was no statistically significant difference in venous outflow between right and left limbs either resting ($p > 0.5$) or after exercise ($p > 0.5$). Both the mean and peak velocities were seen to increase after each exercise in both limbs to a level which was highly statistically significant ($p < 0.001$). There were no statistically significant differences in area of the femoral vein ($p = 0.7$) and peak ($p = 0.5$) or mean blood flow ($p = 0.7$) between opposite limbs in the same individual. Therefore the results were combined to yield an overall sample size of 40 limbs in 20 subjects.

All movements, both passive and active, resulted in an increase in mean and peak blood velocities in the common femoral vein over the established resting levels (Table I), but the active exercises produced greater changes. Passive ‘flexion’ and passive ‘rotation’ caused only moderate increases in mean velocity of 9% (95% CI -1 to +20) and 10% (95% CI 0 to 21), and in peak velocities of 21% (95% CI 12 to 30) and 20% (95% CI 11 to 29), respectively. After the passive combined movement, the 20% (95% CI 9 to 32) increase in mean velocity and the increase in peak velocity of 30% (95% CI 21 to 40), were similar to the corresponding increase produced by active ‘flexion’ of 24% (95% CI 13 to 36) and 33% (95% CI 24 to 43) and by active ‘rotation’ of 24% (95% CI 13 to 36) and 38% (95% CI 28 to 49). The highest blood flow velocities were achieved during the active combined movement which consisted of ankle dorsiflexion and plantar flexion with subtalar inversion and eversion, resulting in circumduction. This produced a mean velocity of blood flow of 39.4 cm/s (95% CI 33.1 to 46.8) and a peak velocity of 70.2 cm/s (95% CI 64.6 to 76.3), representing increases of 38% (95% CI 26 to 52) and 58% (95% CI 47 to 70) respectively, above resting levels.

All of the active and the passive combined movement produced significant increases in both mean and peak measurements when compared with the resting velocity ($p < 0.5$). The mean velocity produced by the active combined exercise was significantly greater than that of passive ‘flexion’, ‘rotation’ or passive combined movement (all $p < 0.5$), and the peak velocity was significantly greater than that of passive flexion and passive rotation ($p < 0.05$).

**Discussion**

It has long been appreciated that early mobilisation decreases the venous stasis which occurs during bed rest after an operation and can therefore help to reduce the risk of thromboembolic complications. There have been no previous studies to document which type and direction of movement would be most beneficial.

Recent studies have shown that the rate of fatal pulmonary embolism after arthroplasty of the lower limb is 0.12%, an order of magnitude lower than previously believed, and that even when prophylaxis is not used, the rate remains low at 0.34%. The use of chemical prophylaxis is associated with a definite incidence of morbidity and mortality due to bleeding complications and many regimes have been shown to be both expensive and ineffective having poor compliance, especially when using combined modalities. Murray et al concluded that “there is no good evidence that any pharmacological agent does more good than harm after a routine total hip replacement” and earlier claims that prophylaxis should be mandatory, have since been put into perspective. In the light of these

<table>
<thead>
<tr>
<th>Movement</th>
<th>Mean velocity</th>
<th>Increase (%)</th>
<th>Peak velocity</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td>28.6 (24.1 to 34.1)</td>
<td>-</td>
<td>44.5 (40.9 to 48.4)</td>
<td>-</td>
</tr>
<tr>
<td>Passive flexion</td>
<td>31.2 (26.2 to 37.1)</td>
<td>6 ( 1 to +20)</td>
<td>53.8 (49.5 to 58.5)</td>
<td>21 (12 to 30)</td>
</tr>
<tr>
<td>Active flexion</td>
<td>35.6 (29.9 to 42.3)</td>
<td>6 ( 13 to 36)</td>
<td>59.0 (54.3 to 64.1)</td>
<td>33 (24 to 43)</td>
</tr>
<tr>
<td>Passive rotation</td>
<td>31.5 (26.5 to 37.5)</td>
<td>10 ( 0 to 21)</td>
<td>53.5 (49.2 to 58.2)</td>
<td>20 (11 to 29)</td>
</tr>
<tr>
<td>Active rotation</td>
<td>35.5 (29.8 to 42.2)</td>
<td>10 ( 13 to 36)</td>
<td>61.6 (56.7 to 67.0)</td>
<td>38 (28 to 49)</td>
</tr>
<tr>
<td>Passive combined</td>
<td>34.4 (28.9 to 40.1)</td>
<td>20 ( 9 to 32)</td>
<td>58.0 (53.3 to 63.0)</td>
<td>30 (21 to 40)</td>
</tr>
<tr>
<td>Active combined</td>
<td>39.4 (33.1 to 46.8)</td>
<td>38 (26 to 52)</td>
<td>70.2 (64.6 to 76.3)</td>
<td>58 (47 to 70)</td>
</tr>
</tbody>
</table>

**Table I.** Mean and peak velocities (cm/s; 95% CI) of blood flow with individual movements for the 20 volunteers.
findings, the views of orthopaedic surgeons appear to be changing,\textsuperscript{3,5} with a reluctance to accept unnecessary and avoidable complications and a resurgence of interest in mechanical methods of prophylaxis.

During anaesthesia and subsequent periods of immobility, blood stagnates in the venous sinuses of the lower limb since the muscle pumps which normally facilitate venous return are inactive. Most DVTs have been shown to arise in these gastrosolealplexuses and many mechanical methods have been designed which aim to promote venous return by promoting the role of the redundant muscle pumps.\textsuperscript{21} One of the most popular methods is the A-V impulse system which was based on the discovery of the mechanism of the venous pump in the sole of the human foot.\textsuperscript{22} Subsequent work showed that venous return could be improved by flattening of the plantar arch causing lengthening of the venae committantes of the lateral plantar arch, which was independent of muscular activity. The A-V impulse system has since been shown to be of value in reducing thromboembolic complications after hemiarthroplasty for fractures of the femoral neck\textsuperscript{23} and total hip\textsuperscript{17,24-27} and total knee arthroplasty.\textsuperscript{28,29} There is a general improvement in the microcirculation with the use of this system,\textsuperscript{26} and it has also been recommended to reduce swelling and compartment pressures after trauma.\textsuperscript{30,31} Patients with arterial disease\textsuperscript{32,33} or chronic venous complaints associated with ulceration\textsuperscript{34} can also benefit from treatment. The drawbacks of mechanical devices include the enforced bedrest and the expensive, specialised equipment. The devices are often bulky or uncomfortable, leading to poor compliance.

In a recent study of the A-V Impulse system by Andrews et al,\textsuperscript{35} the peak velocity of the blood flow in the femoral vein was increased by 21\% when using compression at 50 mmHg, 32\% at 125 mmHg and 38.5\% at 200 mmHg. In our study, active ankle flexion resulted in an increase of 33\% in peak velocity and active subtalar movements and passive combined movements produced an increase of 38\%. The active exercise combining subtalar and ankle movements resulted in an increase in peak flow velocity of 58\% and an increase in mean flow of 38\%, exceeding the reported results of the A-V Impulse system. A further study by McNally, Cooke and Mollan,\textsuperscript{36} investigating the effect of active ankle dorsiflexion and plantar flexion, after total hip replacement, showed an increase of 22\% in mean venous outflow using strain-gauge plethysmography. This was consistent with the increase of 24\% detected in our study when using simple ankle movements. No other movements were studied by McNally et al\textsuperscript{36} and this improvement was less than the increase of 38\% resulting from the combined exercise. Another benefit of active movement is that the improvement in venous haemodynamics is maintained for up to 30 minutes after cessation of exercise.\textsuperscript{36}

The cost-effectiveness of thromboembolic prophylaxis remains an important issue. Calculations which have been widely accepted previously\textsuperscript{37,38} were based on the belief that the rate of fatal pulmonary embolism was 2\% to 3\%.\textsuperscript{1,2,16} These figures have now been shown to be inaccurate, and future estimates based on the lower rates of 0.12\% to 0.34\%\textsuperscript{1,2} must also take into account the cost of setting up and administering a prophylactic regime, together with the costs of morbidity and mortality arising directly as a consequence of its use. It must also be remembered that the use of such a regime does not eliminate thromboembolism and that up to one-third of patients undergoing arthroplasty may still develop a DVT despite its use.\textsuperscript{5} The importance of the plantar venous plexus has been established\textsuperscript{39} but it has been suggested that the venous foot pump may not effectively empty the soleal venous sinuses,\textsuperscript{31} which continue to depend on muscular activity. Our study has shown that active movements are required to promote significant increases in venous blood flow. This may explain the lack of success of the early passive foot-moving devices\textsuperscript{40,41} and the efficacy of graded compression stockings.\textsuperscript{15}

Venous stasis is one of the three components of Virchow’s triad predisposing to thrombosis, and any method which can decrease one of these risk factors without associated morbidity, is clearly worthwhile.

A simple device which encourages patients of any age to move their feet should be inexpensive, reusable, and be readily incorporated into general postoperative rehabilitation. The mechanical device which we describe promotes active contraction of the calf muscles and also produces flattening of the plantar arch as pressure is exerted against the foot-plate during movement. The exercise combining active ankle and subtalar movements produced the greatest increase in mean and peak velocity of blood flow and should therefore be recommended to patients rather than the simple traditional encouragement to ‘keep the toes moving’.

The authors wish to acknowledge the contributions of Mr A. J. Picton, Senior Vascular Research Technologist, who carried out all of the colour-flow Duplex ultrasound assessments; Professor C. N. McCollum, Professor of Vascular Surgery at the University Department of Surgery, Withington Hospital, Manchester, for his advice and permission to use the Vascular Studies Laboratory; and Dr B. Farragher of the Statistical Support Group at the University of Manchester for his advice and for the determination of the statistical analysis.

The authors particularly wish to thank the Arthritis Research Trust, Wrightington Hospital for providing funding for this study.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References


THE JOURNAL OF BONE AND JOINT SURGERY