Movement-related Variation in Forces Under Compression Stockings

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Objectives: compression therapy is widely used in the treatment of venous leg ulcers, but the efficacy of this treatment is variable. Assessment of variation in compression forces associated with movement may help to elucidate the mechanism of action of compression therapy. The aim of this study was to develop and apply a system to investigate forces under compression stockings during movement.

Method: three sensors were placed on the medial aspect of the left leg on six healthy volunteers to monitor forces under class 2 (Continental European classification) compression stockings. Data were recorded during dorsiflexion and plantar flexion of the left foot and also during short periods of walking.

Results: changes in pressure were observed, associated with dorsiflexion and plantar flexion of the foot. These changes were dependent on sensor position. Changes in pressure during walking were also position-dependent and of variable duration.

Conclusions: the system enables forces associated with compression therapy to be examined during movement and may thus be of value in further understanding its mechanism of action. Foot movement can be associated with clear changes in pressure under compression stockings and rapid changes in pressure may occur during walking.

Key words: Compression therapy; Forces; Pressure; Movement.

Introduction

Even though compression therapy has been used for centuries in the treatment of leg ulcers associated with venous disease, its mode of action is still poorly understood. The efficacy of the treatment is variable, which may be due to the previously demonstrated variation in the degree of compression that can be applied. One method for assessing how compression therapy has been applied is to measure the degree of compression. However, it is not clear whether measurement of compression should be performed when the subject is stationary or walking. Ambulatory venous pressure can be elevated in patients with venous ulcers and chronic venous insufficiency (CVI) who may have a limited range of ankle motion. Compression therapy may assist the calf muscle pump by helping to make incompetent valves competent. The performance of the calf muscle pump might thus be affected by variation in compression forces. Thus monitoring forces during movement may help to elucidate the mechanism of action of compression therapy.

A better understanding of the mechanism of action of compression therapy may help to improve treatment efficacy. Thus we have developed and applied a system for ambulatory monitoring of forces achieved by compression therapy. The system, which can detect rapidly changing forces, was used to study forces under compression stockings associated with plantar flexion and dorsiflexion of the foot and when walking.

Aims

The aims of this study were to develop and apply a system for monitoring compression forces during movement and to investigate compression under graduated compression stockings during short periods of walking.

Method

The legs of six healthy volunteers were measured for appropriately-sized standard class 2 (Continental European classification) below-knee graduated compression stockings. There were four male volunteers
and two female volunteers. The median age of the
volunteers was 42 years (range 34 to 52 years). Three
temperature compensated Fontanometer sensors
(Gaeltec Ltd., Isle of Skye, Scotland, U.K.) based on
the strain gauge principle, were used to monitor forces
under the graduated compression stockings.

The sensors, 12.6 mm diameter and 3 mm in height,
were placed on the medial aspect of the left leg. The
first sensor was placed 9 cm above the medial
malleolus (lower), the second where the calf muscle
circumference was most prominent (mid) and the third
on the upper border of the calf muscle (upper). The
sensors were placed directly on the leg, requiring no
liquid column, so that measurements could be made
during movement. The sensors were placed on soft
tissue and not over bone, in order to avoid problems
due to point loading of the sensor which could lead
to misleading results. Thus the measurements were
not made, for example, over the medial malleolus.

Each sensor was connected via an amplifier to an
analogue to digital converter in a notebook computer.
The forces were expressed as pressure and the signals
sampled at 400 Hz per channel. The system was cal-
ibrated in an air chamber and in a water column.

Pressures were recorded during short periods of
standing followed by walking 2 or 3 steps. The position
of both feet was simultaneously monitored during
walking with two force sensing resistors (FSR) placed
on the sole of each foot. A graph of the variation in
pressure for each volunteer was printed with a colour
printer. The printouts were used to assess the baseline
pressure and maximum variation in the standing po-
tion prior to walking. The peak pressures seen on
each sensor during the short periods of walking were
also evaluated from the graphs for each volunteer. The
subjects then sat on a bench with both legs horizontal.
Pressures were recorded during maximal dorsiflexion
and plantar flexion of the left foot. A colour graph
printout for each volunteer was again obtained. The
absolute pressure with the legs horizontal prior to
dorsiflexion and plantar flexion of the left foot was
evaluated. In addition, for each volunteer, the greatest
change from the baseline during dorsiflexion and
plantar flexion was evaluated from the graphs.

Results

The calibration of the sensors showed close agreement
when calibrated in the water column or air chamber
with a mercury manometer, giving a maximum dif-
ference of ±3 mmHg. A graph illustrating the agree-
ment for one of the sensors in the air chamber is shown
in Fig. 1.

The pressures recorded, when standing, at the lower,
mid- and upper sensors are shown in Table 1. Thus
the pressure at the lower sensor was greater than the
upper sensor in four of the volunteers. In all volunteers
the pressure on the mid-placed sensor was greater
than the lower sensor. When standing, the maximum
variation in the analysed graphs was <4 mmHg for
each volunteer except subject 6, where the maximum
variation was <8 mmHg. The maximum increase in
pressure during walking is also shown in Table 1. Thus
it can be seen that the highest increase in pressure
during walking was observed on the mid-placed
sensor. An example of changes in pressure associated
with walking is shown in Fig. 3.

During walking, the highest pressure at the mid-
and lower sensor occurred as the weight distribution
changed from the left heel to the metatarsal heads. A
clear short transient change in pressure was seen whilst
moving onto the left heel in four subjects on the lower
sensor, in five subjects on the mid- and in three subjects
on the upper sensor. These transient changes in pres-
sure were less than 0.25 s in duration.

There were clear changes in forces associated with
plantar flexion and dorsiflexion of the foot as shown
in Table 2. An example of these changes is shown in
Figure 2. The changes in pressure were dependent on
sensor position. The pressure change associated with
dorsiflexion was most marked on the mid-placed
sensor.

![Fig. 1. Example of comparison of sensor with manometer using an air chamber. Figure 1b shows difference (manometer reading–sensor system reading) against manometer reading.](image-url)
Table 1. Absolute pressure observed at the lower, mid and upper sensors, when subjects were standing, and maximum observed increase during walking.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Lower</th>
<th>Mid</th>
<th>Upper</th>
<th>Lower</th>
<th>Mid</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31</td>
<td>41</td>
<td>20</td>
<td>+8</td>
<td>+26</td>
<td>+2</td>
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<tr>
<td>2</td>
<td>26</td>
<td>38</td>
<td>25</td>
<td>+5</td>
<td>+22</td>
<td>+9</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
<td>43</td>
<td>31</td>
<td>+12</td>
<td>+23</td>
<td>+7</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
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<td>23</td>
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<tr>
<td>6</td>
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<td>50</td>
<td>30</td>
<td>+14</td>
<td>+68</td>
<td>+3</td>
</tr>
<tr>
<td>Median</td>
<td>28.5</td>
<td>42</td>
<td>25.5</td>
<td>+8.5</td>
<td>+22.5</td>
<td>+4</td>
</tr>
</tbody>
</table>

Discussion

Previous studies using a variety of compression stockings have observed that the pressure profile under compression stockings is not necessarily strictly graduated, which is in accordance with our study. The observed pressure profile is likely to depend upon the positions at which pressure is monitored. For example, the pressure under compression stockings near to ankle level has been found to vary around the leg.

In our study, when the volunteers were standing the greatest pressure was observed at the position of most prominence in the calf muscle. This may be because this is likely to be the position where the tension in the stocking is greatest. Since the calf muscle shape, position and the shape of the leg may vary between individuals, it would be expected to be difficult to compensate for such variations without having custom-made stockings. In our study, the pressure at the lower transducer was greater than the pressure at the upper transducer for four of the six volunteers when standing. It is difficult to predict how the observed variation in surface pressure along the leg influences the pressure around the veins because of the varying cross-section and different tissue bulk.

Measuring forces associated with compression therapy with a sensor of finite dimensions may cause some disturbance to local forces and, thus, in order to

Table 2. This table shows the absolute pressure with the subjects sitting with legs raised and the greatest change in pressure (in mmHg) observed during dorsiflexion and plantar flexion. For the pressure changes, a positive value indicates an increase in pressure and a negative value indicates a decrease in pressure.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Absolute pressure when sitting with legs raised (mmHg)</th>
<th>Pressure change dorsiflexion (mmHg)</th>
<th>Pressure change plantar flexion (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower  Mid  Upper</td>
<td>Lower  Mid  Upper</td>
<td>Lower  Mid  Upper</td>
</tr>
<tr>
<td>1</td>
<td>16  24  23</td>
<td>+9  +11  −5</td>
<td>−5  +4  +8</td>
</tr>
<tr>
<td>2</td>
<td>20  29  32</td>
<td>+5  +17  −9</td>
<td>0  −2  +3</td>
</tr>
<tr>
<td>3</td>
<td>15  28  28</td>
<td>+9  +25  −3</td>
<td>+2  +4  +7</td>
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<td>4</td>
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<td>+2  +1  −2</td>
<td>0  −4  +5</td>
</tr>
<tr>
<td>5</td>
<td>34  33  23</td>
<td>+11  +7  −3</td>
<td>−1  +5  +12</td>
</tr>
<tr>
<td>6</td>
<td>29  41  20</td>
<td>+21  +27  0</td>
<td>−9  +29  +8</td>
</tr>
<tr>
<td>Median</td>
<td>21.5  28.5  25</td>
<td>+9  +14  −3</td>
<td>−0.5  +4  +7.5</td>
</tr>
</tbody>
</table>
minimise any disturbance, it is important to use a low-profile sensor. The sensor used in this study, although of low profile, may cause some effect on forces under the stockings. However, any such effect should be consistent and thus should not significantly affect the variations in pressure observed.

Clear changes in pressure under compression stockings associated with plantar flexion and maximal dorsiflexion of the foot and during walking were observed. The changes associated with maximal dorsiflexion appeared to be more consistent than changes associated with plantar flexion. This may be because it is easier to perform the maximal dorsiflexion than plantar flexion.

The fast transients observed during walking demonstrate that the force changes have several components and do not vary in a simple fashion. Marked increases in pressure gradient were observed during walking between mid and upper levels and between lower and upper levels. These changes may contribute to the calf muscle pump and thus influence ambulatory venous pressure. It could therefore be postulated that limitation of movement of the ankle reduces the level of maximal pressure or pressure variation achieved while walking.

Acknowledgement

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References


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