Influence of Support Stockings on Photoplethysmography (PPG) Recovery Time in Venous Insufficiency*

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ABSTRACT Photoplethysmography (PPG) was used to assess the effect of support stockings on 11 limbs with superficial saphenous insufficiency and on 23 limbs with deep venous insufficiency. Forty normal limbs served as controls. Every limb was examined with and without above knee surgical weight elastic support stockings. Limbs with superficial and deep venous insufficiency had shorter PPG recovery times (superficial = 17.3 ± 0.9 sec; deep = 12.4 ± 1.1 sec) than did control limbs (40.4 ± 3.2; p < 0.01). Elastic support stockings resulted in a significant (p < 0.01) increase in PPG recovery time in both superficial (29.2 ± 2.9) and deep venous insufficiency limbs (23.2 ± 1.9 sec) but did not change recovery time in control limbs (41.5 ± 2.7 sec). These results support the concept that surgical support stockings function by compressing superficial veins inhibiting early venous refill through incompetent deep and superficial valves and provides a means of assessing the adequacy of elastic stocking fit.

Introduction

The clinical benefits of elastic stockings for treating venous insufficiency are widely accepted. Nonetheless, there are surprisingly few studies which have objectively assessed the physiologic effects of external elastic compression with stockings.1-6 The lack of a non-invasive and simple method for evaluation has undoubtedly contributed to this incomplete documentation. Previously used techniques have included venous pressure measurements1-2 and venography3 as well as cumbersome and less specific non-invasive methods such as foot volumetry.7

Photoplethysmography has been useful in evaluation of venous valvular function. A good correlation has been demonstrated between PPG recovery time and direct venous pressure measurements.1 To evaluate the physiologic effect of elastic stocking compression on skin hemodynamics, we measured PPG recovery time with and without elastic support hose.

Materials and Methods

Twenty healthy volunteers (40 limbs) without clinical evidence of varicose veins, venous insufficiency or a previous history of deep venous thrombosis served as controls (Group I). These individuals had an average age of 26 years (range 25-30 yrs.). Twenty-two patients with venous insufficiency were studied. These included 6 males and 16 females with a mean age of 51 years (range 21-84 yrs.). Varicose veins were present in all patients, four had previous venous ulceration, seven had stasis dermatitis, and 15 had leg edema. Seven patients had a history of prior deep venous thrombosis. Photoplethysmography was performed on both legs of each patient and was found to be abnormal in 34 of the 44 limbs. Each abnormal limb was categorized into superficial venous insufficiency (n = 11, Group II) or deep venous insufficiency (n = 23, Group III).

Venous Doppler examination was performed on both controls and patients to ensure the absence of acute deep venous thrombosis. Brachial/ankle systolic pressure index was normal in all patients and control subjects.

Photoplethysmography was performed under standardized conditions as described by Abramowitz et al.1 The subject was seated on the side of the bed with legs dependent and relaxed, and a phototransducer was placed approximately 2 cm. posterior and superior to the medial malleolus with double-stick transparent tape. The patient was then asked to dorsiflex and plantarflex his ankle once per second for 5 seconds to augment venous return and empty the cutaneous venules and capillaries, resulting in a downward deflection of the PPG tracing.1 Cutaneous venous refill by arterial inflow or venous reflux resulted in a return of the PPG tracing to the resting baseline. The time to return to baseline or to achieve a new baseline for at least 5 seconds was established as the recovery time. These times were recorded to the nearest 0.5 second for each trial and the mean of the five exercise trials was taken as the recovery time for each patient. A PPG recovery time equal to or longer than 23 seconds was considered normal.1 A PPG recovery time less than 20 seconds was considered to be

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abnormal and indicative of venous valvular incompetence. Limbs with abnormal recovery times were subdivided into superficial and deep venous valvular incompetence on the basis of sequential tourniquet application according to the algorithm outlined in Figure 1. Using this testing sequence, 11 limbs were classified as having superficial valvular incompetence (Group II) and 23 limbs were classified as having deep venous valvular incompetence (Group III).

![Diagram of Algorithm for differentiating Deep and Superficial Venous Insufficiency.]

Each limb was then reexamined by PPG in the same manner with a properly fit above knee surgical weight, elastic support stocking (Bauer & Black extra high compression). Stockings were selected and fit according to the manufacturer’s specifications. The photocell was carefully placed beneath the support stocking and care was taken not to disturb it. The dorsiflexion, plantarflexion exercise trials were repeated in the manner as without stockings and PPG recovery time calculated as the mean of 5 trials.

The results are given as mean ± SEM. Statistical analysis was performed using the Student’s t-test for paired or unpaired data. Significance was assumed if p was less than 0.05.

**Results**

PPG recovery time for limbs with superficial venous insufficiency was 17.3 ± 0.9 seconds and for limbs with deep venous insufficiency was 12.4 ± 1.1 seconds. Both were significantly shorter than recovery time in control limbs, 40.4 ± 3.2 seconds (p<0.01). PPG recovery time was most abnormal in the limbs with deep venous insufficiency as evidenced by a 28% faster recovery time than in the limbs with superficial venous insufficiency.

When elastic support stockings were used, PPG recovery time in normal control limbs did not change. However, in limbs with superficial venous insufficiency, (Group II) the mean PPG recovery time increased 69% from 17.3 seconds to 29.2 seconds (p <0.01) and in limbs with deep venous insufficiency (Group III) mean recovery time increased 87% from 12.4 seconds to 23.2 seconds (p<0.01). Both Groups II and III increased recovery time to within normal range. The difference in PPG recovery time for Groups II and III with elastic support compression was not statistically different, suggesting that both Groups had benefited from elastic support stocking compression.

**Discussion**

The hemodynamic effects of support stockings in patients with venous insufficiency has been evaluated using phlebography, radioisotope clearance and venous pressure measurements. Phlebograms have demonstrated a general reduction of the venous pool, compression of superficial varices, improved venous return, and better filling of the deep veins with gradient pressure stockings. Jones et al. have shown that sodium subcutaneous tissue clearance was significantly improved by compression stockings both at rest and with exercise. Direct venous pressure measurements, have not produced consistent results with respect to the effectiveness of support stockings in reducing resting and ambulatory venous pressures.

The principle non-invasive method used to record the changes in venous hemodynamics with support stockings has been foot volumetry. These studies have demonstrated a significant improvement in recovery time following exercise. The recent introduction of photoplethysmography has provided an additional non-invasive method which directly assesses cutaneous circulation. Photoplethysmography has been used to diagnose venous insufficiency and to evaluate the results of interventional therapy, but has not previously been used to evaluate support stockings.

A potential methodologic concern in using PPG to evaluate support hose involves the positioning of the transducer beneath the elastic stockings. It is possible that increased pressure of the transducer against the skin caused by stockings may alter the recovery time. In our study we placed the transducer in the standard position above the medial malleolus where the benefit of a stocking would be considered to be the greatest. The bulk of the photocell added approximately 5/16 of an inch to the ankle circumference, which did not exceed the manufacturer’s specified range for the stockings used in our evaluation. No alteration in PPG recovery time was noted in our control limbs with or without stockings, suggesting that the changes noted when stockings were applied to abnormal limbs were not merely artifacts.

The present study suggests the elastic support stockings delay early refilling of the cutaneous microcirculation in limbs with incompetent deep or superficial valvular systems. This hemodynamic effect on the cutaneous circulation may account for the observed clinical benefit of support stockings. The PPG recov-
Table I

PPG Recovery Time (seconds) in Groups I, II, and III.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Photoplethysmography Recovery Time (seconds)</th>
<th>P</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Without Stockings</td>
<td>With Stockings</td>
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<tr>
<td>I</td>
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<td></td>
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<tr>
<td>Normal</td>
<td>40</td>
<td>$40.4 \pm 3.2$</td>
<td>$41.5 \pm 2.7$</td>
</tr>
<tr>
<td>II</td>
<td>11</td>
<td>$17.3 \pm 0.93$</td>
<td>$29.2 \pm 2.9$</td>
</tr>
<tr>
<td>III</td>
<td>23</td>
<td>$12.4 \pm 1.19$</td>
<td>$23.2 \pm 1.9$</td>
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Mean recovery time $\pm$ SEM

Photoplethysmography Recovery Time Without [□] and With [■]

Figure 2.

ery time has been shown to parallel changes in direct venous pressure and to be a good reflection of venous reflux.¹ Thus improvement of PPG recovery time with stocking compression appears to be a good indicator of improved venous hemodynamics in patients with venous insufficiency and may be applicable to quantitatively assess adequacy of stocking fit.

Conclusion

Photoplethysmography provides a simple, non-invasive method for documenting venous insufficiency and may be applicable to quantitate assessment of support stockings in reducing early refilling of the microcirculation in patients with valvular incompetence. Clinical application of PPG may permit better selection of patients in need of elastic support hose and may provide a means of detecting poor stocking fit.

References