Influence of high-heeled shoes on venous function in young women

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Background: Walking with high-heeled shoes is a common cause of venous complaints such as pain, fatigue, and heavy-feeling legs. The aim of the study was to clarify the influence of high-heeled shoes on the venous return and test the hypothesis that women wearing different styles of high-heeled shoes present an impaired venous return when compared with their values when they are barefoot.

Methods: Thirty asymptomatic women (mean age, 26.4 years) wearing appropriately sized shoes were evaluated by air plethysmography (APG), a test that measures changes in air volume on a cuff placed on the calf, while they performed orthostatic flexion and extension foot movements and altered standing up and lying down. The test was repeated in four situations: barefoot (0 cm), medium heels (3.5 cm), stiletto high heels (7 cm), and platform high heels (7 cm). The APG values of venous filling index (VFI), ejection fraction (EF), and residual volume fraction (RVF) were divided into four groups according to heel height and compared by repeated-measures analysis of variance.

Results: RVF was increased in the groups wearing high heels (stiletto and platform) compared with the barefoot group (P < .05). RVF was increased in the medium-heel group (3.5 cm) compared with the barefoot group (P < .05), and despite the lack of statistical significance, the medium-heel group showed lower values of RVF compared with the two high-heel groups. The EF parameter followed the opposite tendency, showing higher values for the barefoot group compared with the other three groups (P < .05). Values for VFI were similar in the three situations evaluated.

Conclusions: High heels reduce muscle pump function, as demonstrated by reduced EF and increased RVF values. The continuous use of high heels tends to provoke venous hypertension in the lower limbs and may represent a causal factor of venous disease symptoms. (J Vasc Surg 2012;56:1039-44.)

The influence of high-heeled shoes on venous function is a controversial subject. Ergonomics is an important factor for quality of life and health, and its impairment, such as prolonged standing, shoe quality, and workplace conditions may interfere with the individual’s health.1 Ergonomics and workplace conditions, including posture, type of shoe, and floor stiffness, can provoke symptoms such as heavy legs and lumbar and plantar pain. These facts were confirmed by electromyography of the legs and the effect of shoes and pressure sensors tests.1-3

Previous studies have used air plethysmography (APG) to demonstrate the correlation between leg fatigue and increased leg volume in workers with hard-soled shoes standing for a prolonged time.4 Heel hardness and thickness also influence the formation of the calcaneus spur.5 However, other factors such as walking speed and biophysical constitution also contribute to symptoms such as pain and fatigue. Shorter individuals with higher body mass index are also more susceptible.6-7

The Ethics Committee of the host institution approved this study. After a comprehensive explanation of the proposed study, its benefits, and expected time commitments, all participants gave written informed consent.

Study participants. The study recruited 30 women (mean age, 26.4 years) from the host institution. They were free of any evident symptoms or signs of disease and underwent a careful physical examination. The inclusion criteria were (1) women clinically free of any venous disease, as classified on CEAP with C0 or C1, (2) body mass index <25 kg/m², (3) age between 20 and 35 years, and (4) signed informed consent.

APG assessment. The women were examined with APG, a test that measures changes in air volume on a cuff placed on the calf, during orthostatic flexion and extension foot movements (tiptoe movements) and postural changes. APG (SDV 3000; Angiotech, Belo Horizonte, Brazil) can obtain important information about venous filling and return. It uses a low-pressure air-filled cuff measuring 30 to 40 cm in length that is applied to the lower leg from knee to ankle. The cuff is connected to a plethysmograph that is highly sensitive to volume changes in the cuff, allowing...
precise quantitative evaluation of volume changes of the entire leg from knee to ankle.

Initially, the volunteer lies supine with the leg elevated and supported at the heel, which allows the cuff to be applied to the lower leg. The cuff is inflated to a pressure of 6 mm Hg to provide snug apposition to the limb without compressing the superficial veins. A baseline volume is obtained with the participant resting supine. The volunteer then moves to a standing position, supported by a walker to remove weight from the left tested limb. The volume tracing gradually increases until a plateau is reached. The volunteer is asked to distribute the weight equally for the two legs, relaxing without any support, and then performs one calf contraction in a tiptoe maneuver, followed by rest. A subsequent series of 10 tiptoe maneuvers completes the test procedure (Fig 1).

The tracings obtained from each test permit acquisition of several venous function parameters:

1. Venous filling index (VFI)—evaluation of the global health of the lower limb given by valvar competence. VFI is calculated by measuring 90% of venous volume (VV) and dividing this volume by the time the limb requires to refill to 90% of VV after moving to the standing position (mL/s).

2. Ejection fraction (EF)—evaluation of the venous return during calf contraction. EF determines if the muscle pump is performing properly or not. It is acquired from the volume of blood ejected with one tiptoe movement divided by VV.

3. Residual volume fraction (RVF)—This parameter is closely related to ambulatory venous pressure (AVP). It indirectly represents AVP in a linear way, as shown in previous studies. Therefore, it has been used as a non-invasive method to determine the venous pressure on the superficial venous system. It is acquired by calculating the limb volume remaining after 10 tiptoe movements divided by VV.

Some values for these parameters are very well clinically established. Generally accepted normal values for VFI are <2 mL/min; higher values are associated with venous reflux. It is considered normal when EF >40%, and lower levels are related to muscle pump failure and venous ulcers. Finally, RVF values are considered normal when <35%. Christopoulos and Nicolaides have pointed that the incidence of venous ulcer is 0% when RVF <30% and 88% when RVF >80%.

Experimental design. Each participant was clinically free of any venous disease and was examined in a scheduled audition during which the APG assessment was repeated four times as follows: Participant barefoot, wearing 3.5-cm high-heeled shoes, wearing 7-cm stiletto high-heeled shoes, and finally, wearing 7-cm platform high-heeled shoes (Fig 1). Just the left leg was evaluated because the participants could more easily use the right leg, without any assisting device, to get the standing position and to lie down freely.

A description of the differences between a 7-cm stiletto heel and a 7-cm platform “Annabelle” heel is important. The former kind, in shoes with flexible soles, allows two regions of shoe contact with the ground: the front (toes and metatarsals) and the rear (calcaneus). In contrast, the platform heel allows the inflexible sole to touch the ground completely (Fig 2). There is better plantar flexion and a worse stability during walking with stiletto heel. The platform Annabelle heel permits a better sense of comfort because it offers better stability but restricts plantar movements because the sole is rigid.

Pilot tests of several kinds of shoes for each of the high-heeled shoe groups were initiated to find the shoe styles that would permit the better tiptoe maneuver experience with a perfect adaptation and fixation of the feet with the sole. The latter must be observed because some shoe styles with an inadequate fixation could allow uncontrolled ankle joint excursion and thus defeat the experiment. In some of the discarded models, the foot, particularly the heel, came out of the shoe and allowed a greater excursion at the ankle joint and therefore more activation of the calf muscle pump.

The best three “standard” types—a 3.5-cm medium heel, 7-cm platform Annabella heel, and 7-cm stiletto heel—were chosen based on this criteria. The different degrees of ankle joint excursion among the shoe types were not measured for each participant.

To ensure that the 3.5-cm heel is the first high-heeled shoe that results in a range of ankle excursion that could interfere with venous function, a wide range of high-heeled shoes must be tested, increasing about 0.5 cm for each one, and until the very first one that presents values out of acceptable clinical ranges is found. Considering these difficulties, this study used 3.5-cm and 7-cm heels because they are more commonly used among women.

The participants were instructed to refrain from rigorous physical activity for at least 4 hours before the assessments. The participant was placed supine, at rest with legs lifted on a 20-cm-high support for 5 minutes between each of the four tests. The vascular function indices, VFI, EF, and RVF were then determined in each APG examination.

Data analysis. A total of 120 plethysmographic tracings were obtained, on which VFI, EF, and RVF parameters were recorded and compared in four groups (barefoot, high-heeled shoes with 3.5-cm heels, WITH 7-cm stiletto heels, and with 7-cm platform Annabelle heels).

Statistical analyses were performed using SPSS 11.0 software (SPSS Inc, Chicago, Ill) and SAS 9.0 software (SAS Institute, Cary, NC). Data are reported as mean ± standard deviation (Table). To examine differences in the APG indexes VFI, EF, and RVF, a repeated-measure design (analysis of variance) with subsequent pairwise comparisons was used. Duncan’s post-test was applied to check which pair was significantly different. Values were considered significant at P < .05.
RESULTS

The values of VFI, EF, and RVF obtained with the individuals barefoot, wearing 3.5-cm heels, wearing 7-cm stiletto heels, and wearing 7-cm platform heels are presented in the Table. The lowest mean EF values were found in both groups wearing the shoes with 7-cm heels (55.09% for stiletto-heeled shoes and 51.34% for platform-heeled shoes). The highest mean value for this parameter was found in the barefoot group.

The lowest mean RVF value was found in the barefoot group (35.26%) and the highest in the 7-cm high-heeled groups (56.12% for shoes with stiletto heels and 59.44% for platform heels). The mean EF and RVF values for the group wearing shoes with 3.5-cm high heels were intermediate.

Fig 1. A, A volunteer resting in the air plethysmography examination room. B, The air plethysmography cuff has been applied to the volunteer’s left leg during calibration. C, Registering venous filling with the volunteer standing barefooted. D, Tiptoe movements contracting the calf. E, Volunteer using device support for better calf relaxing after acquiring ejection volume wearing a 7-cm high-heeled shoe. Volunteer lifting and contracting calf with the three different heels studied: (F) 3.5 high-heeled shoes, (G) 7-cm high-heeled stiletto shoes, and (H) 7-cm high-heeled platform shoes.
Therefore, EF was decreased and RVF was increased in both of the 7-cm high-heeled groups compared with the barefoot group \((P < .05)\). RVF was significantly increased in the 3.5-cm high-heeled group compared with the barefoot group \((P < .05)\), but with no difference compared with higher heels. There was no difference between the two 7.0-cm high-heeled groups for this parameter. VFI showed a similar behavior (no statistical differences) in the four groups evaluated (Figs 3-5).

There was an important decrease in EF simultaneously with an increase in RVF with the increase in heel height.

**Table.** Venous function parameters in each one of the four situations

<table>
<thead>
<tr>
<th>Venous parameter</th>
<th>No.</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barefooted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VFI</td>
<td>30</td>
<td>1.05 ± 0.59</td>
</tr>
<tr>
<td>EF</td>
<td>30</td>
<td>71.51 ± 27.11</td>
</tr>
<tr>
<td>RVF</td>
<td>29</td>
<td>35.26 ± 14.62</td>
</tr>
<tr>
<td>3.5-cm heeled shoe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VFI</td>
<td>30</td>
<td>0.98 ± 0.62</td>
</tr>
<tr>
<td>EF</td>
<td>30</td>
<td>68.01 ± 23.83</td>
</tr>
<tr>
<td>RVF</td>
<td>30</td>
<td>49.33 ± 25.39</td>
</tr>
<tr>
<td>7-cm stiletto-heeled shoe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VFI</td>
<td>30</td>
<td>0.93 ± 0.5</td>
</tr>
<tr>
<td>EF</td>
<td>30</td>
<td>55.09 ± 20.76</td>
</tr>
<tr>
<td>RVF</td>
<td>30</td>
<td>56.12 ± 23.98</td>
</tr>
<tr>
<td>7-cm platform-heeled shoe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VFI</td>
<td>30</td>
<td>0.9 ± 0.44</td>
</tr>
<tr>
<td>EF</td>
<td>30</td>
<td>51.34 ± 21.03</td>
</tr>
<tr>
<td>RVF</td>
<td>30</td>
<td>59.44 ± 23.85</td>
</tr>
</tbody>
</table>

*EF*, Ejection fraction; *RVF*, residual volume fraction; *SD*, standard deviation; *VFI*, venous filling index.
Platform heels seem to be worse for calf venous pumping in all four situations tested (Fig 6.)

DISCUSSION

The influence of high-heeled shoes on venous return has not been previously investigated by applying the same APG standard indices used in vascular clinical practice. Since 2005, our group has been using APG to clarify this issue. After presenting initial results to the scientific community, we realized how interesting this study could be if we compared more than one height of heel and different shapes of heels and soles. Potério-Filho et al studied the effect of walking with high-heeled shoes on leg venous return. Using a new method of venous pressure evaluation by APG, they observed that the variation in cuff pressure during walking with high-heeled shoes was higher than the variation in cuff pressure when walking barefoot. Thus, they concluded that walking with high-heeled shoes could reduce leg venous pressure compared to walking barefoot.

The present study showed that the lowest mean EF values were found in both groups wearing 7-cm high-heeled shoes and the highest mean EF value was found in the barefoot group. In contrast, the lowest mean RVF was found in the barefoot group and the highest mean RVF was found in both 7-cm high-heeled groups.

EF and FVR values found in both groups wearing 7-cm high-heeled shoes are out of the ranges considered clinically normal, what may be interpreted as a time-limited unhealthy exposition that is as long as the period that the high-heeled shoes are worn.

These findings led us to different conclusions than those reached by Potério-Filho et al. Considering universally accepted APG indices and the range of values for these parameters, the present study indicated that high heels have a deleterious action on the muscle pump of the lower limbs.

Barton et al studied the effect of heel lifts on trunk muscle activation during gait in young healthy women. Heel lifts are a treatment option for low back pain, while at the same time high-heeled shoes have been linked to low back pain development. The cited study evaluated the effects of in-shoe 20-mm-high bilateral heel lifts on trunk muscle activity. Using surface electromyography in 15 participants, they observed that the heel lifts altered muscle activity reactively around the heel strike, with greater muscle activity after heel use. The data obtained by Barton et al agreed with the proposition of Potério-Filho et al of increased muscle effort but did not automatically indicate a better venous return, because muscle effort is only related to systole and does not consider the importance of diastole during calf muscle pumping.

Reczek considered the prerequisites for a perfect function of the calf muscle venous pump: patent and competent deep lower leg veins, patent outflow tract, and unrestrained motion of the ankle joint. The values obtained with this study for the barefoot group were into the standard range expected for healthy individuals, whereas these same individuals presented abnormal RVF and EF values when high-heeled shoes were worn. This occurred because the motion of the ankle joint is temporarily restrained, tending to decrease venous return. In contrast, the deep lower leg veins and valves and the outflow tract were intact, as confirmed by the normal VFI values in all four groups.

One could note a tendency of worst calf muscle pump performance when the participants wore high-heeled platform shoes compared with other three groups. The high-heeled platform shoe restricts more plantar and ankle joint movements, leading to higher RVF, but this study did not find a statistical difference between the stiletto and platform groups (Fig 6).

CONCLUSIONS

The temporary use of high-heeled shoes reduced calf muscle pump function, as demonstrated by the decrease in EF and increase in RVF. These findings show that the higher the heel, the worse the calf pump performance secondary to restrained motion of the ankle joint. The continuous use of high-heeled shoes is prone to cause higher levels of RVF, which means higher venous pressure in the leg. Venous hypertension is related to deleterious
consequences such as varicose veins and undesirable symptoms.

AUTHOR CONTRIBUTIONS
Conception and design: WT, ND, EJ, TM, CP
Analysis and interpretation: WT, CP
Data collection: WT
Writing the article: WT
Critical revision of the article: WT, CP
Final approval of the article: WT, CP
Statistical analysis: WT
Obtained funding: WT
Overall responsibility: WT

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