The impact of intermittent pneumatic compression devices on deep venous flow velocity in patients with congestive heart failure

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Summary
Background: Intermittent pneumatic compression (IPC) has been used to prevent deep venous thrombosis (DVT), but the effects of IPC on the hemodynamics of popliteal and soleal veins, especially in patients with congestive heart failure (CHF) have not been evaluated. The aim of this study was to evaluate the effects of IPC on the flow velocity of deep veins in the lower extremities and to compare the efficacy of two different types of IPC in deep venous flow enhancement in patients with CHF.

Methods: Flow velocities of popliteal and soleal veins were recorded in 19 patients with CHF and in 19 control subjects using a high-resolution linear probe. Peak and mean flow velocities were measured (1) at rest, (2) with sequential foot and calf IPC (SFC-IPC) which consists of an electrically driven air compressor and four air chambers, and (3) with impulse foot IPC (IF-IPC) which consists of a pneumatic impulse generator operated at an applied pressure of 130 mmHg.

Results: In the resting condition, popliteal venous flow velocity in the CHF group was attenuated ($12.8 \pm 4.7$ cm/s vs. $21.1 \pm 13.5$ cm/s; $p < 0.05$). Both SFC-IPC and IF-IPC increased venous velocity, but the increase with IF-IPC in CHF patients was lower than that in control subjects. In the soleal veins, after applying SFC-IPC, the peak and mean velocity in CHF increased to the same extent as in the control group. IF-IPC increased soleal venous velocity in control subjects, but there was no increase in CHF patients.
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foot and calf IPC (SFC-IPC) are widely used in a clinical

have been used as an established method to prevent DVT in

units. The effects of IPC on venous hemody-

amics have been evaluated [7,8]. Although the theoretical

concern was that IPC might increase in venous return to the

heart, a previous study demonstrated that the application

of IPC did not alter any central hemodynamic parame-

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amics in the popliteal and common femoral veins in

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vein has not been evaluated, particularly in patients with

CHF. Furthermore, which type of IPC is more effective

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unknown. The present study was designed to evaluate the

effects of IPC on the flow velocity of popliteal and soleal

veins and to compare the efficacy of two different types

of IPC in deep venous flow enhancement in patients with

CHF.

Introduction

Congestive heart failure (CHF) is recognized as one of the

major risk factors for deep venous thrombosis (DVT) in the

lower extremities [1–4] and subsequent venous thromboem-

bolism (VTE). The symptoms and signs of heart failure (HF),

based on low cardiac output and elevated left and right

ventricular (LV and RV) filling pressure, such as dyspnea

on exertion, palpitation and leg edema, are usually more

noticeable than VTE and commonly hinder its detection [3].

Vascular duplex scanning imaging, obtained with a high-

resolution probe, revealed that DVT was most commonly

detected in deep small veins, especially the soleal vein

[5,6]. Although a reduced LV ejection fraction (LVEF) and

stasis of venous flow in patients with CHF was thought to be

the main reason for thrombogenesis in deep veins, the flow

dynamics of lower extremity veins have not been fully eval-

uated. Intermittent pneumatic compression devices (IPC)

have been used as an established method to prevent DVT in

intensive care units. The effects of IPC on venous hemody-

amics have been evaluated [7,8]. Although the theoretical

concern was that IPC might increase in venous return to the

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veins and to compare the efficacy of two different types

of IPC in deep venous flow enhancement in patients with

CHF.

Methods

Subjects

Venous flow was measured in the popliteal and soleal veins

in 19 patients with CHF (9 male, 10 female; mean age 54.9

years) and 19 control subjects (9 male, 10 female; mean

age 51.8 years). The enrolled CHF patients were admitted
to our hospital for treatment of acute aggravation of HF.

CHF was diagnosed by clinical manifestation, and physical

and objective examinations based on LV systolic dysfunction,

diastolic dysfunction, or both. Severity of CHF according to

the New York Heart Association (NYHA) functional class was

more than III. The central venous pressure in the CHF group

was recorded with a central venous catheter. Inferior vena
cava (IVC) collapsibility was also evaluated by ultrasonogra-

phy as a marker of venous stasis [4]. Positive collapsibility

was defined as respiratory change in IVC diameter of >50%

[4]. The etiology of CHF in this cohort included ischemic

heart disease, dilated cardiomyopathy, valvular disease, and

dilated-phase hypertrophic cardiomyopathy (Table 1). None

of the control subjects had any history or clinical evidence of

HF, venous dysfunction, VTE, DVT or other major risk factors

for VTE.

Study design

The flow velocities of the popliteal and soleal veins were

measured using a high-resolution linear probe (13 MHz)

interfaced with an ultrasound unit (SSD-10, Aloka, Tokyo,

Japan). A custom-made probe holder was used to hold the

probe without excess compression on the deep veins

throughout the study. The Doppler angle was maintained at

less than 55°. Soleal venous flow was measured from the

posterior side of the leg with the subject in the prone posi-

tion. The popliteal venous flow was obtained approximately

2 cm cephalad to the small saphenous vein junction with all

subjects in the prone position. Venous flow velocities of the

popliteal and soleal veins were measured in patients with

CHF and control subjects: (1) at rest; (2) with SFC-IPC (Veno

Stream 601-J, Terumo, Tokyo, Japan); and (3) with IF-IPC

(AV impulse, Kobayashi Medical, Osaka, Japan) (Fig. 1). The

SFC-IPC consisted of an electrically driven air compressor

and four air chambers that were inflated sequentially from

the sole to the knee in approximately 10 s. The inflation

started with a slow increase in pressure in each air cham-

ber. This procedure was repeated every 60 s. The pneumatic

compression pressure was adjusted to 50 mmHg. The IF-IPC

consisted of a pneumatic impulse generator and a plas-

tic inflatable foot pad. This system operated at an applied

pressure of 130 mmHg, a deflation pressure of 0 mmHg, an

inflation time of 1 s, and a frequency of 3 impulses per

minute (Fig. 1).

Statistical analysis

Values are expressed as mean ± standard deviation. The

mean values were compared using the Student’s t test for

unpaired variables and Fisher’s protected least significant

difference test. Differences were considered significant if

they exceeded the 95% confidence level (p < 0.05). All sta-

tistical calculations were conducted using Stat-View, version

5.0 (SAS Institute Inc., Cary, NC, USA).

The study protocol was approved by the Institutional

Review Board at Yamaguchi University Hospital. Written

informed consent was obtained from all participants prior
to entering the study.
Table 1  Baseline characteristics of the control subjects and patients with congestive heart failure.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Control (n = 19)</th>
<th>CHF (n = 19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years), mean (SD)</td>
<td>51.8 (16.2)</td>
<td>54.9 (15.1)</td>
</tr>
<tr>
<td>Male (%)</td>
<td>47.4</td>
<td>47.4</td>
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<tr>
<td>Medications</td>
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<tr>
<td>Warfarin (%)</td>
<td>0</td>
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</tr>
<tr>
<td>Aspirin (%)</td>
<td>0</td>
<td>36.8*</td>
</tr>
<tr>
<td>Ticlopidine (%)</td>
<td>0</td>
<td>21.1*</td>
</tr>
<tr>
<td>Diuretic (%)</td>
<td>0</td>
<td>89.4</td>
</tr>
<tr>
<td>ACEi (%)</td>
<td>0</td>
<td>57.9*</td>
</tr>
<tr>
<td>ARB (%)</td>
<td>0</td>
<td>36.8*</td>
</tr>
<tr>
<td>β blocker</td>
<td>0</td>
<td>73.7*</td>
</tr>
<tr>
<td>Steroid (%)</td>
<td>0</td>
<td>15.8*</td>
</tr>
<tr>
<td>Echocardiography</td>
<td></td>
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</tr>
<tr>
<td>LVDD (mm)</td>
<td>45.6 (3.8)</td>
<td>60.4 (10.6)*</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>65.2 (7.7)</td>
<td>35.0 (14.8)*</td>
</tr>
<tr>
<td>RV-RA PG (mmHg)</td>
<td>16.6 (2.3)</td>
<td>41.4 (13.1)*</td>
</tr>
<tr>
<td>IVC diameter (mm)</td>
<td>13.9 (3.8)</td>
<td>21.6 (2.4)*</td>
</tr>
<tr>
<td>IVC collapse (%)</td>
<td>100</td>
<td>15.8*</td>
</tr>
<tr>
<td>Other findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central venous pressure (mmHg)</td>
<td>—</td>
<td>11.8 (2.0)</td>
</tr>
<tr>
<td>BNP (pg/mL)</td>
<td>—</td>
<td>827.7 (611.5)</td>
</tr>
<tr>
<td>Cardiac conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischemic heart disease (%)</td>
<td>0</td>
<td>31.6*</td>
</tr>
<tr>
<td>Dilated cardiomyopathy (%)</td>
<td>0</td>
<td>26.3*</td>
</tr>
<tr>
<td>Valvular disease (%)</td>
<td>0</td>
<td>26.3*</td>
</tr>
<tr>
<td>Other heart disease (%)</td>
<td>0</td>
<td>15.8*</td>
</tr>
</tbody>
</table>

CHF, congestive heart failure; SD, standard deviation; ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; LVDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; RV-RA PG, pressure gradient between right ventricular and right atrium; IVC, inferior vena cava; BNP, brain natriuretic peptide.  

* p < 0.01 vs. control subjects.

Figure 1  Intermittent pneumatic compression devices. (A) Sequential foot and calf intermittent pneumatic compression device (Veno Stream 601-J unit, Terumo, Tokyo, Japan): the device consists of an electrically driven air compressor and four air chambers, which are inflated sequentially from the sole (1) to the knee (4) in 10 s. (B) Impulse foot intermittent pneumatic compression device (AV impulse, Kobayashi Medical, Osaka, Japan): the device consists of a pneumatic impulse generator and one plastic inflatable foot pad. This system operated at applied pressure of 130 mmHg, deflation pressure 0 mmHg and inflation time 1 s.

SFC-IPC, sequential foot and calf intermittent pneumatic compression device; IF-IPC, impulse foot intermittent pneumatic compression device.
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The effects of two intermittent pneumatic compression devices on popliteal and soleal venous flow velocities. Popliteal (A) and soleal (B) venous flow velocities in control subjects and in patients with CHF. With SFC-IPC, the venous flow velocity increased in the quad-phase in both groups with sequential inflation of the air chambers from the sole to the knee. With IF-IPC, the venous flow velocity rose rapidly and decreased within a short time.

C, control subjects; CHF, congestive heart failure; SFC-IPC, sequential foot and calf intermittent pneumatic compression device; IF-IPC, impulse foot intermittent pneumatic compression device.

Results

The LV end-diastolic diameter, RV-atrial pressure gradient, and diameter of the IVC were greater and LVEF was smaller in the CHF group compared with the control group. The mean central venous pressure in the CHF group was 11.8 ± 2.0 mmHg. The collapsibility of the IVC in CHF patients was markedly poorer than in control subjects (15.8% vs. 100%, p < 0.01) (Table 1).

Effects of IPC on venous flow

Representative changes of the venous flow waveform in popliteal (A) and soleal veins (B) in control subjects and in patients with CHF after applying the IPC at expiration are shown in Fig. 2. With SFC-IPC, the venous flow velocity increased in the quad-phase with sequential inflation of the air chambers from the sole to the knee in both groups. With IF-IPC, the venous flow velocity rose rapidly and decreased within a short time.

Popliteal vein

In the resting condition, popliteal venous flow velocity in the CHF group was attenuated (12.8 ± 4.7 cm/s vs. 21.1 ± 13.5 cm/s; p < 0.05) (Fig. 3). Application of SFC-IPC increased the peak and mean velocity of the popliteal vein in both control subjects and in patients with CHF. Although application of IF-IPC increased peak popliteal velocity compared with rest in both groups (Table 2), the magnitude of the increased venous flow with IF-IPC was smaller than that with SFC-IPC (Table 2). Furthermore, augmentation of peak flow velocity with SFC-IPC in CHF patients was the same as in control subjects. However, the increase in peak flow velocity with IF-IPC in CHF patients was significantly lower than in control subjects (Fig. 3).

Soleal vein

In the resting condition, there were no differences in the peak and mean velocity in the soleal veins between the CHF and control groups (peak: 4.3 ± 3.0 cm/s vs. 3.5 ± 1.8 cm/s; mean: 2.4 ± 1.9 cm/s vs. 2.0 ± 0.9 cm/s; both p = not significant [NS]). After applying SFC-IPC, the peak and mean velocity of the soleal vein in CHF patients increased to the same level as in the control group (peak: 77.9 ± 30.4 cm/s vs. 71.1 ± 19.9 cm/s; mean: 18.0 ± 7.7 cm/s vs. 19.8 ± 8.6 cm/s; both p = NS) (Fig. 4). IF-IPC increased the peak soleal venous velocities com-
Figure 3  The peak velocities of the popliteal vein with or without intermittent pneumatic compression. Peak popliteal venous flow was attenuated in patients with CHF at rest. The SFC-IPC increased peak flow velocity of the popliteal vein in patients with CHF as well as in control subjects, but the increased velocity with IF-IPC in CHF patients was lower than that in control subjects.

CHF, congestive heart failure; SFC-IPC, sequential foot and calf intermittent pneumatic compression device; IF-IPC, impulse foot intermittent pneumatic compression device.

Table 2  Changes in popliteal venous flow velocity after applying intermittent pneumatic compression devices.

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>SFC-IPC</th>
<th>IF-IPC</th>
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<tbody>
<tr>
<td>C</td>
<td>Peak velocity (cm/s)</td>
<td>21.1 ± 13.5</td>
<td>110 ± 41.5†,‡</td>
</tr>
<tr>
<td></td>
<td>Mean velocity (cm/s)</td>
<td>12.7 ± 8.4</td>
<td>41.5 ± 25.6†,‡</td>
</tr>
<tr>
<td>CHF</td>
<td>Peak velocity (cm/s)</td>
<td>12.8 ± 4.7</td>
<td>85.6 ± 31.8†,‡</td>
</tr>
<tr>
<td></td>
<td>Mean velocity (cm/s)</td>
<td>6.6 ± 2.6</td>
<td>27.6 ± 10.6†,‡</td>
</tr>
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</table>

C, control subjects; CHF, congestive heart failure; SFC-IPC, sequential foot and calf intermittent pneumatic compression device; IF-IPC, impulse foot intermittent pneumatic compression device.

*  p < 0.01 vs. rest.

†  p < 0.05 vs. rest.

‡  p < 0.01 vs. IF-IPC.

Figure 4  The peak velocities of the soleal vein with or without intermittent pneumatic compression. There was no difference between peak soleal venous velocities in control subjects and in patients with CHF in the absence or presence of IPC devices.

CHF, congestive heart failure; SFC-IPC, sequential foot and calf intermittent pneumatic compression device; IF-IPC, impulse foot intermittent pneumatic compression device.

Discussion

The present study illustrated the effect of different types of intermittent pneumatic compression devices on deep venous flow velocity in CHF patients. The most notable findings were as follows: (1) the peak flow velocity of the popliteal vein was attenuated in CHF patients; (2) after application of SFC-IPC and IF-IPC, peak popliteal venous flow velocities in control subjects and in CHF patients increased compared with those at rest; however, for IF-IPC, the increase in velocity in CHF patients was less than in control subjects;

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>SFC-IPC</th>
<th>IF-IPC</th>
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<tbody>
<tr>
<td>C</td>
<td>Peak velocity (cm/s)</td>
<td>3.5 ± 1.8</td>
<td>71.1 ± 19.9†,‡</td>
</tr>
<tr>
<td></td>
<td>Mean velocity (cm/s)</td>
<td>2.0 ± 0.9</td>
<td>19.8 ± 8.6†,‡</td>
</tr>
<tr>
<td>CHF</td>
<td>Peak velocity (cm/s)</td>
<td>4.3 ± 3.0</td>
<td>77.9 ± 30.4†,‡</td>
</tr>
<tr>
<td></td>
<td>Mean velocity (cm/s)</td>
<td>2.4 ± 1.9</td>
<td>18.0 ± 7.7†,‡</td>
</tr>
</tbody>
</table>

C, control subjects; CHF, congestive heart failure; SFC-IPC, sequential foot and calf intermittent pneumatic compression device; IF-IPC, impulse foot intermittent pneumatic compression device.

*  p < 0.01 vs. rest.

†  p < 0.05 vs. rest.

‡  p < 0.01 vs. IF-IPC.
Although SFC-IPC increased soleal venous flow in both groups, IF-IPC failed to significantly increase soleal venous flow in CHF.

DVT in CHF

It was reported that the occurrence of DVT in the lower extremities was related to the severity of CHF [1–3,11], and that the risk of VTE increased as LVEF decreased: the odds ratio for VTE increased from 2.8 to 38.3 with a decrease in LVEF from 45 to 20% [1], and the risk of DVT and VTE increased according to NYHA functional class [4,12]. Furthermore, another study demonstrated that abnormal platelet function (levels of soluble P-selectin and von Willebrand factor) as well as high plasma viscosity contributed to a hypercoagulable state in CHF patients with more severe NYHA class [13].

Deep venous flow velocities in patients with CHF

Many investigators have attempted to detect DVT by measuring the peak venous velocity in the superficial femoral vein using venous duplex ultrasound [7,14]. Recently, advances in a high-resolution linear probe have revealed that DVT was most commonly detected in deep veins, particularly the soleal vein [5,6]. Thus, we focused on the venous flow velocities in soleal as well as popliteal veins.

This study revealed that popliteal venous flow velocity was lower in CHF patients than in control subjects. Venous flow velocity in lower extremity is affected by cardiac output, right atrial pressure, respiration, and calf contraction exercise [1,15,16]. The attenuation of popliteal venous flow velocity in CHF patients may be affected by increase in right atrial pressure. On the other hand, the soleal venous flow velocity even in control subjects was as low as the velocity in CHF patients in the resting condition (Table 3; Fig. 4). The soleal veins are peripheral veins and course beneath soleus muscle. Because soleal veins are small in diameter, these veins may be compressed by the muscle in lower limbs and the venous flow velocities may be low even in healthy subjects. In CHF patients, the reduction in cardiac output and elevated right atrial pressure may facilitate peripheral circulatory insufficiency in the lower extremities and may increase the risk of DVT. In contrast, because an increase in venous flow velocity with ankle and leg exercise in healthy subjects is expected [15,16], the incidence of DVT may be low in these subjects.

Effects of IPC on deep venous flow

IPC is recognized as a prophylactic device against DVT [7–10,17,18], and the guidelines for the prevention of VTE in 2008 recommended IPC as one of the most useful devices for prevention of VTE [19]. In this study, both SFC-IPC and IF-IPC augmented peak velocity in popliteal veins in control and CHF subjects. SFC-IPC also augmented the soleal venous velocity in both groups. On the other hand, IF-IPC slightly increased soleal venous velocity in control subjects but not in CHF patients. This different response to the two devices on soleal venous velocity may be accounted for by the anatomy of the plantar venous plexus and deep veins: the plantar venous plexus diverges into an outflow of one to four veins that flow into the posterior tibial venous system and into the popliteal vein [20]. The soleal vein also flows into the popliteal vein via the peroneal vein and not from the plantar venous plexus. A previous study reported that IF-IPC increased peak velocity in the posterior tibial veins but not in the anterior tibial and peroneal veins [20]. This report supported that IF-IPC might not increase venous flow in the soleal vein, which is not contiguous with the plantar venous plexus. The SFC-IPC compresses the lower extremity from the sole to the knee, increasing the velocity step-by-step with inflation of each air chamber. This device also may increase venous flow in the deep veins and provide sufficient improvements in venous clearance to help prevent venous hemostasis and thrombogenesis in CHF patients.

Study limitations

In this study, we did not evaluate changes in venous diameter while applying the IPC. Thus, we could not ascertain changes in the amount of venous flow before and during the application of IPC. Nevertheless, the radial shape of the vein is affected by venous pressure, the amount of venous return, and venous compression from surrounding tissues; therefore, evaluation of the venous diameter throughout the study may be unreliable. Our results suggested a prophylactic mechanism of IPC in thrombogenesis. However, we did not observe whether DVT was prevented by IPC in CHF patients. Further follow-up study is needed to confirm the prophylactic effects of these devices in CHF patients.

Conclusions

Two-dimensional Doppler scanning with a high-resolution linear probe revealed a significant increase in mean and peak velocities in the soleal and popliteal veins on application of SFC-IPC but not of IF-IPC in patients with CHF. These results indicate that SFC-IPC is likely to have a favorable effect in preventing DVT in patients with CHF.

Acknowledgments

We are indebted to Yukari Kishida, Tomoko Ezumi, and Hiroko Tsutsumi for skilled technical assistance.

References