Venous duplex scanning of the leg: range, variability and reproducibility

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ABSTRACT

Despite the many studies on venous haemodynamics using duplex, only a few evaluated the normal values, variability and reproducibility. Therefore, the range and variability of venous diameter, compressibility, flow and reflux were measured. To obtain normal values, 42 healthy individuals (42 limbs, 714 vein segments) with no history of venous disease were scanned by duplex. To determine the reproducibility the intra-observer variability was measured in 11 healthy individuals (187 vein segments) and the inter-observer variability in 15 healthy individuals (255 vein segments) and 13 patients (169 vein segments) previously diagnosed with deep venous thrombosis. Of the 714 normal vein segments, 708 (99%) were traceable, including the crural veins. Of the traceable vein segments, 675 (95%) were compressible and in 696 (98%) flow was present. Of the 42 common femoral vein segments, in 25 (60%) the reflux duration exceeded 1.0 s, but in the other proximal vein segments the reflux duration was less than 1.0 s (95% confidence interval 3.0–10.0). With the exception of the distal long saphenous vein, in the distal vein segments the reflux duration was less than 0.5 s (95% confidence interval 3.5–8.2). The coefficient of variation of the diameter measurements ranged from 14 to 50% and that of the reflux measurements from 28 to 60%. The $k$-coefficient of the inter-observer variability in the classification of compressibility measurements in the patients was 0.77 and that of the reflux measurements was 0.86. This study shows that almost all veins were compressible in healthy individuals, except the distal femoral veins. In healthy individuals the duration of reflux of the proximal veins was less than 1.0 s and in the distal veins it was less than 0.5 s. The inter-observer variability of the reflux and compressibility measurements in the patients was good.

INTRODUCTION

Duplex scanning, measuring the compressibility of the veins, has proved to be an important method for diagnosis of deep venous thrombosis (DVT) [1,2]. Nowadays duplex is frequently used for the follow-up of DVT [3,4] and to assess the development of the post-thrombotic syndrome [5–8]. Duplex scanning may be used to provide anatomical information such as changes in the diameter of the vein segments [9–13] or haemodynamic information such as the presence of reflux and flow [5,14,15]. The venous system is very complex and affected by
many physiological factors. Respiration, position and central venous pressure can all alter the diameter of the veins. The arterial inflow and the calf muscle pump may have an impact on reflux measurements. Despite many studies performed by duplex, few have evaluated normal values and variability and reproducibility of the measurements [9,11,16], although it is widely accepted that duplex is very operator-dependent. This makes results in diameter changes or reflux measurements in numerous studies difficult to interpret. Therefore, in this study the range, variability and reproducibility of venous diameter, compressibility, flow and reflux were measured by duplex scanning.

METHODS

To evaluate the range of diameter, compressibility, flow and reflux, 42 healthy individuals (42 limbs, 714 vein segments) with no history of DVT or a chronic venous disease, were scanned by duplex. To establish the reproducibility the intra-observer variability was measured in 11 healthy individuals (187 vein segments) and the inter-observer variability in 15 healthy individuals (255 vein segments) and 13 patients (169 vein segments) previously diagnosed with DVT. Proximal DVT in these patients was diagnosed by ultrasound and distal DVT by phlebography, 1 month to 2 years before these measurements.

The inter-observer variability was obtained by comparing measurements performed by two vascular technicians, blinded for each other’s results, in 15 healthy individuals. The intra-observer variability was obtained by comparing two measurements performed by one vascular technician in 11 healthy individuals. The minimal time period between the measurements by the same technician was 1 day.

In the patients the peroneal and gastrocnemial veins were not measured because in the healthy individuals these measurements appeared to be time-consuming or difficult and their clinical importance is probably limited. In the two patients with recent thrombosis only compressibility was measured, not reflux.

The study was approved by the ethics committee of the hospital and informed consent was obtained from all participants.

Duplex

Duplex scanning was performed by two experienced vascular technicians using a Toshiba SSA 270A scanner with a 3.75 or 5 MHz probe in low-flow setting (minimum measurable velocity 2 cm/s). All veins were examined with the individual in a 45° sitting position, the knee flexed and the feet resting on a footstool. The veins examined were the common femoral vein, the superficial femoral vein (proximal, middle and distal), the long saphenous vein (proximal, middle and distal), the popliteal vein, the short saphenous vein, the posterior and anterior tibial veins, and the peroneal and gastrocnemial veins. In the calf two veins accompany each artery. The two veins were numbered, number 1 being the most superficial and number 2 the deeper vein.

In the longitudinal plane the presence of venous flow and reflux was measured. Proximally, reflux was measured after the Valsalva manoeuvre and in the distal veins by distal manual compression with sudden release. The diameters and compressibility were assessed in the transverse plane. A vein was considered non-compressible when the vein was not totally compressed with gentle pressure by the duplex probe applied to the skin overlying the vein.

A vein was considered not traceable when the vein was not visible by B-mode in transverse plane and when it was not possible to measure any flow velocity by colour and Doppler in the longitudinal plane.

Statistical evaluation

Means and standard deviations were calculated. The range of reflux in the healthy individuals was expressed as 95% confidence intervals because in some vein segments the reflux duration was too long to measure and therefore indefinite. The coefficient of variation (CV) was used to evaluate the variability of the diameter and reflux measurements. The CV was expressed as a percentage since the measurement error increased with the value.

\[
CV^2 = \frac{(a_i - b_i)^2}{m_i^2} \cdot \frac{1}{2n}
\]

where \(a_i\) = observer 1, \(b_i\) = observer 2 and \(m_i\) = mean (\(a_i, b_i\)).

The inter-observer agreement in the classification of compressibility and reflux in patients was expressed by the \(k\)-coefficient.

\[
k = \frac{O - C}{1 - C}
\]

where \(O\) = observed agreement and \(C\) = chance agreement.

RESULTS

Range

Table 1 shows the characteristics of the healthy individuals and patients.

Table 2 shows the diameters, compressibility and presence of flow in the 42 healthy individuals. Of the 714
Table 1  Characteristics of healthy individuals and patients for the different substudies
Age is expressed as mean (range).

<table>
<thead>
<tr>
<th></th>
<th>Healthy individuals</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Intra-observer variability</td>
</tr>
<tr>
<td>No.</td>
<td>42</td>
<td>11</td>
</tr>
<tr>
<td>Age (years)</td>
<td>47 (21–78)</td>
<td>31 (21–50)</td>
</tr>
<tr>
<td>% female (n)</td>
<td>55 (23)</td>
<td>64 (7)</td>
</tr>
<tr>
<td>% right legs (n)</td>
<td>59 (25)</td>
<td>45 (5)</td>
</tr>
</tbody>
</table>

Table 2  Diameters, compressibility and presence of flow in 42 healthy individuals
Diameters are expressed as means (S.D.). Superf. = superficial.

<table>
<thead>
<tr>
<th>Vein segments</th>
<th>n</th>
<th>Diameter (mm)</th>
<th>Not compressible</th>
<th>No flow present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common femoral</td>
<td>42</td>
<td>13.7 (2.8)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Superf. femoral proximal</td>
<td>42</td>
<td>9.2 (1.8)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Superf. femoral half</td>
<td>42</td>
<td>8.2 (1.5)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Superf. femoral distal</td>
<td>42</td>
<td>8.5 (1.4)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Popliteal</td>
<td>42</td>
<td>8.9 (1.8)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Long saphenous proximal</td>
<td>42</td>
<td>5.0 (0.9)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Long saphenous half</td>
<td>41</td>
<td>4.0 (1.0)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Long saphenous distal</td>
<td>42</td>
<td>3.0 (0.6)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Short saphenous</td>
<td>41</td>
<td>2.9 (1.0)</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Posterior tibial 1</td>
<td>42</td>
<td>3.3 (0.6)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Posterior tibial 2</td>
<td>42</td>
<td>3.5 (0.7)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anterior tibial 1</td>
<td>42</td>
<td>2.4 (0.5)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Anterior tibial 2</td>
<td>41</td>
<td>2.3 (0.6)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Peroneal 1</td>
<td>40</td>
<td>3.0 (0.8)</td>
<td>6*</td>
<td>0</td>
</tr>
<tr>
<td>Peroneal 2</td>
<td>41</td>
<td>3.0 (0.9)</td>
<td>7*</td>
<td>0</td>
</tr>
<tr>
<td>Gastrocnemial 1</td>
<td>42</td>
<td>3.2 (1.0)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gastrocnemial 2</td>
<td>42</td>
<td>2.9 (0.7)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>708</td>
<td>33</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

* Impossible to evaluate the compressibility.

vein segments, 708 (99%) were traceable, including the crural veins. Of the traceable vein segments, 675 (95%) could be assessed as compressible and in 696 (98%) flow was present. In all 13 distal femoral vein segments that were not compressible flow was present. Two short saphenous and three distal long saphenous vein segments were not compressible and showed no flow. In the non-compressible peroneal vein segments the resolution of the B-mode image made it impossible to evaluate the compressibility, because the vein wall was not visible.

Figures 1 and 2 show the range of reflux in the proximal and distal vein segments respectively. Reflux was defined as a rounded number, as close as possible to the 95% confidence interval, which might be easy in practical use. Of the 42 common femoral vein segments, in 25 (60%) the reflux duration exceeded 1.0 s, but in the other proximal vein segments the reflux duration was less than 1.0 s (95% confidence interval 3.0–10.0). With the exception of the distal long saphenous vein, in the distal vein segments the reflux duration was less than 0.5 s (95% confidence interval 3.5–8.2). The values for duration of reflux that exceed 2500 ms were actually indefinitely long.

### Variability and reproducibility

Figures 3 and 4 plot the diameter difference for the proximal and distal vein segments respectively against the mean of two observers in the 13 patients and 15 healthy individuals.

Figures 5 and 6 plot the reflux difference in the proximal and distal vein segments respectively against the
Figure 1  Duration of reflux in proximal veins in 42 healthy individuals, measured using the Valsalva manoeuvre

Figure 2  Duration of reflux in distal veins in 42 healthy individuals, measured using distal compression

Figure 3  Diameter difference (D1 – D2) of proximal veins against the mean of two observers in 15 healthy individuals and 13 patients

Figure 4  Diameter difference (D1 – D2) of distal veins against the mean of two observers in 15 healthy individuals and 13 patients
Reproducibility of venous duplex

Figure 5 Reflux difference ($R_1 - R_2$) of proximal veins against the mean of two observers in 15 healthy individuals and 13 patients.

Figure 6 Reflux difference ($R_1 - R_2$) of distal veins against the mean of two observers in 15 healthy individuals and 13 patients.

mean of two observers in the 13 patients and 15 healthy individuals.

Table 3 shows the CV of the diameter and reflux measurements for the proximal and distal vein segments.

In the patients, 57 of the 169 vein segments (34%) were not compressible and 43 of the 143 vein segments (30%) had reflux. The majority of the pathology was located in the proximal veins. The $\kappa$-coefficient of the inter-observer agreement in the classification of compressibility in patients was 0.77 (0.78 in the proximal veins, 0.87 in the distal veins) and in normal subjects it was 1, except for the distal superficial femoral vein.

Reflux was classified using the ranges as shown in Figures 1 and 2. Proximally an abnormal reflux was defined as a reflux duration of more than 1.0 s, distally more than 0.5 s. The $\kappa$-coefficient of the inter-observer agreement using this classification of reflux in patients was 0.86 (0.85 in the proximal veins, 0.87 in the distal veins) and in normal subjects it was 1, except for the proximal superficial vein and the short saphenous vein.

In the 15 normal subjects 252 of the 255 (99%) traceable veins were compressible and 237 of the 240 (99%) had no reflux by both observers.

DISCUSSION

The most evaluated parameter of the venous system using duplex is the compressibility of the veins in the diagnosis of DVT. In our study the inter-observer agreement of these measurements in patients appeared to be good ($\kappa = 0.77$), despite the fact that 30% of the distal femoral vein segments in healthy individuals were not compressible and therefore might have caused misinterpretation of compressibility in patients. This is probably due to the deep course of this vein segment as it enters Hunter’s canal. Similar observations have also been reported by others [1,17]. Flow was present in all of these non-compressible distal femoral vein segments. If compressibility had been used as the sole criterion for thrombosis, these vein segments would have given a false positive result and therefore the use of simultaneous Doppler in this segment is important. Five superficial vein segments in the healthy individuals were non-compressible and showed no flow because they were probably totally occluded. This shows that even in healthy individuals without signs of venous disease, small thrombi might be present in superficial veins.

In 13 of the 81 (16%) peroneal veins the resolution of the B-mode image made it impossible to evaluate compressibility. In almost all of these veins (97%) it was possible to observe the presence of flow. So Doppler measurements might be helpful in the diagnosis of crural vein thrombosis. Previous reports have already shown that the use of compression ultrasonography alone in the crural veins is difficult to interpret [18,19] and not as

<table>
<thead>
<tr>
<th>Table 3</th>
<th>The coefficient of variation (CV) of the diameter and reflux measurements in distal and proximal veins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proximal diameter</td>
</tr>
<tr>
<td>CV</td>
<td></td>
</tr>
<tr>
<td>Intra-observer, healthy individuals</td>
<td>14%</td>
</tr>
<tr>
<td>Inter-observer, healthy individuals</td>
<td>15%</td>
</tr>
<tr>
<td>Inter-observer, patients</td>
<td>15%</td>
</tr>
</tbody>
</table>
reliable as when applied to the proximal veins [19], due to the small diameters and location.

There is still no consensus about the technique of inducing reflux and the appropriate cut-off time to define pathological reflux. Reflux can be induced by performing a Valsalva manoeuvre [6], by compression of the limb [6,19] or with the cuff deflation technique as described by van Bemmelen et al. [5]. In previous studies patients were examined in the standing position [5,19], in the sitting position [19] or in the reversed Trendelenburg position [6]. Cut-off times of abnormal reflux times vary from 0.5 s [5,8,20,21] up to 2 s [6,22,23].

A method to induce reflux that is well evaluated is the cuff deflation technique. This technique has some disadvantages: an automatic cuff inflator must be present, the patients have to be examined in the standing position and it is difficult to scan the entire length of the veins. Other studies [15,24] have shown that the Valsalva technique detects a similar proportion of reflux in the proximal veins as the cuff deflation technique. The technical advantages, comfort for the patient and simplicity are arguments in favour of the Valsalva technique in the examination of proximal veins. Since there is no consensus about the cut-off time, position of the patient and variability using the Valsalva technique, these elements were evaluated in our study. The most recent publication using the cuff deflation technique [8] describes a duration of reflux in the proximal deep veins in 95% of the healthy individuals of approximately 0.8 s. This is in accordance with the findings of our study.

It was suggested that the effect of the Valsalva manoeuvre diminishes in the distal limb veins [15]. Although some authors report that reflux in the calf veins cannot be reliably measured with any technique [24], others used manual compression to induce reflux in distal veins [16]. Manual compression appeared to be as reliable as the cuff technique to identify reflux [14] in the popliteal vein and was therefore used in our study. The duration of reflux in the distal veins of healthy individuals in our study was similar to that found with the cuff technique [5].

Of the 42 common femoral vein segments, in 25 (60%) the reflux duration exceeded 1.0 s, and 22% even exceeded a reflux duration of 2.0 s. In the study of Basmajian [25] about 33% of the common femoral veins had no valve and therefore reflux seems physiological. Also, in 14% of the distal long saphenous veins the reflux duration exceeded 0.5 s. Thus, reflux in one vein segment can be present in healthy individuals without complaints, as also observed by others [19].

The CV for the diameter measurements of the proximal veins was large (15%). This indicates that only major diameter changes can be measured reliably. For example, in the common femoral vein this would be a change of 6 mm and in the popliteal vein a change of 4 mm. In the distal veins the CV varied even more; due to the small diameters a change in diameter cannot be reliably measured. It is known that many variables can affect the venous diameter [26]. In our study the most important variable, the examination position, was standardized. Other variables such as temperature or time of measurement were not standardized. This in order to approach the daily reality in which examinations are performed. Also, the measurements were performed using a duplex scanner with a resolution power of 1 mm. The resolution power of current ultrasound machines is much better (about 0.5 mm) which might decrease the variability, especially in the smaller veins.

The CV for the reflux measurements also varied. Usually the actual reflux time is not measured, but rather a cut-off time of pathological reflux. Using the cut-off time as defined in our study, the ω-coefficient of the inter-observer variability of the reflux measurements was 0.86. This shows that the measurement can be of practical use, despite the large CV.

Scanning as many veins as we did is time consuming: the examination of diameter, compressibility, flow and reflux of 17 vein segments in one leg requires approximately 45 min. Therefore, in this study, the entire length of the calf veins was not scanned.

The difference in the inter-observer CV in the distal veins in patients and healthy individuals might be because in the patients the gastrocnemial and peroneal veins were not measured. The measurements of gastrocnemial and peroneal veins in healthy individuals appeared to be very difficult and therefore the variability in these veins was high.

In conclusion, this study shows that almost all veins are compressible in healthy individuals, except the distal femoral veins. The variability of diameter and reflux measurements was large. The inter-observer variability of the compressibility measurements in the patients was good. The normal duration of reflux in the proximal veins was less than 1.0 s and in the distal veins it was less than 0.5 s. The inter-observer variability of the reflux measurements was good.

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REFERENCES


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