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Where should stiffness be measured *in vivo*?

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Abstract

Three points in the medial aspect of the leg are routinely used to measure the interface pressure of a compression: the C point, at the largest circumference of the calf; the B point, at the smallest circumference of the leg; the *anatomical* B1 point, at the apex of the gastrocnemius muscle and the *manufacturer's* B1 point, computed in the midline of the line joining the B point to the C point). The *anatomical* B1 point is the most reliable point from a practical point of view, and is easier to use. The underlying anatomy is the Soleus muscle. Stiffness at the *anatomical* B1 point seems adequate sufficient to assess stiffness of a medical device *in vivo*.

Introduction

In laboratory the stiffness of a medical compression device is defined as the pressure change (in mmHg) that occurs with an increase in circumference of one centimeter ($\Delta P/\Delta C$). *In vivo*, this is very difficult to measure. For this reason the static stiffness index (SSI) proposed by Partsch *et al.*[1] is used as a rough estimate of stiffness. By definition, SSI is calculated by substracting the interface pressure (in mmHg) in the lying position from the interface pressure (in mmHg) in standing position. Compression devices are defined as *stiff* if SSI is 10 mmHg or more. Another stiffness index has also been proposed: the dynamic or dorsiflexion stiffness index (DSI) calculated by substracting the diastolic from the systolic interface pressure (in mmHg) during dorsiflection, while lying down.[2] Although slightly higher, the values of the DSI are similar to those of the SSI.

Anatomical review of the venous muscular pumps

The muscular pumps of the lower limb represent the peripheral heart of the venous system. They push blood upward against gravity, so that downward reflux can be prevented by normally functioning valves. The main muscular pump of the lower limb is the calf pump. It is divided into two parts: i) the soleus muscle pump which works at the leg level. The soleal veins are divided into two parts, lateral and medial. The lateral veins are bigger and drain, vertically, into the fibular veins. The smaller medial veins drain horizontally into the posterior tibial veins; ii) the gastrocnemius muscle pump which works at the popliteal level. The medial part of the muscle and the medial gastrocnemius veins are very important. These veins originate by the gastrocnemius perforators, connecting end-to end at the apex of the calf. Two or three big veins form a network inside the muscle, which join in a unique collector ending in the popliteal vein.

The main reference points of the leg

Four points in the medial aspect of the leg are routinely used to measure the interface pressure of a compression device,[3] all situated at the medial aspect of the leg (Figure 1). These are: i) the C point (at the largest circumference of the calf); ii) the B point (at the smallest circumference of the leg); iii) the *anatomical* B1 point (*B1a* at the apex of the gastrocnemius muscle); iv) lastly, the *manufacturer's* B1 point (*B1m* in the midline of the line joining the B point to the C point).

Figure 2 shows a realistic 3D anatomical model, reconstructed by a multi-slice computed tomography (MSCT). This medial view demonstrates that, below the apex of the medial gastrocnemius, the Soleus muscle is the main muscle of the underlying anatomy. This muscle represents the deeper part of the triseps suralis (calf pump muscle).

Figure 3 shows that the *anatomical* B1 point which is easily found by a simple clinical exam during the muscular contraction of the calf.

Objectives

The aims of this studies were: i) to verify if these reference points are reliable; ii) to assess their variability; iii) to assess the optimal site for calculating stiffness: at the anatomical B1 point, the C point, or both; iv) to compare stiffness with two different short stretch bandages.

Materials and Methods

We performed three different studies: a clinical study on 22 healthy subjects to localize reference points, a radiological computed tomography venography (CTV) study with MSCT was performed on 19 patients to assess the anatomical landmarks of the leg, and a study assessing stiffness by two compression devices applied on ten legs.

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Clinical study to localize reference points: measurements of the legs of 22 healthy subjects (17 women and five men) were done in the *standing position.* The evaluations included the measure of the distance of the B and C points from the ground, the distances of the *anatomical* B1 and *manufacturer's* B1 points from the ground, and the height of the subject.

Study by CT venography to assess the anatomical landmarks of the leg:[4] MSCT scanning was performed with a Siemens SOMATOM® Definition Flash 64 slice CT scanner, with contrast injection into a dorsal foot vein. The CT parameters were acquisition from feet to head, 120 KV, and 150 mAs. Reconstruction parameters: slice width 1 mm, slice increment 0.75, matrix 512×512, zoom factor 1.7. Post processing was performed with the volume rendering technique by OsiriX 64-bit, version 5 (Pixmeo company, www.osirix.foundation.com) Nineteen patients (thirteen women and six men) were investigated in the *lying position* before varicose vein surgery. Measurements were made using the OsiriX software on the 3D reconstructed images. Localization of the C, B, B1a, and B1m points were made and the distances between the points were computed, as well. The length of the tibia was considered to be equal to the distance from knee joint to the apex of the medial malleolus.

Clinical study to assess the stiffness of two compression devices: the stiffness of two compression devices was assessed in 23 healthy legs. Rosidal K™ (Lohmann & Rauscher), was applied to eleven legs and Coban™2 (3M™) to twelve. Rosidal K™ (Lohmann & Rauscher) is a short stretch bandage (5 m × 10 cm). The bandage was applied in a circular way with full

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stretch. Coban™2 is a two layer bandage consisting in a padding layer (10 cm × 2.7 m) and a short stretch bandage (10 cm × 4.7 m). The two bandages were applied according to the recommendations of the manufacturer. Each bandage being overlapped by 65%. Bandages were applied so that a target pressure of 40 mmHg at the *anatomical* B1 and C points could be achieved. The interface pressure was measured with a Kikuhime® device (Makoto TAKAHASHI and Sanae, Biomedical Systems Engineering, Graduate School of Engineering, Hokkaido University, Japan), using the small probe, in the lying position, at rest and during muscular contraction, and in the standing position (Figures 4 and 5).

Statistical methods

We used StatView, version 5 (Copyright 1998 SAS institute inc., USA), to compute the mean and standard deviation (σ) of the samples and to determine the median for interface pressures.

Results

Clinical measurement

The height from the ground was measured for the C point (at the largest circumference of the calf), the B1a point (at the apex of the gastrocnemius muscle), and the B1m point (in the midline of the line joining the B point to the C point), and distances between these points were all measured on 22 healthy subjects. Results are shown in Table 1. The mean distance B1a-C was 5.66 cm [standard deviation (SD) 1.76] and the mean distance B1a-m was 3.95 cm (SD 1.87). There was no correlation between the distances observed and the height of the subject.

Computed tomography venography anatomical measurement

The same parameters were measured by CTV on 19 patients before varicose vein surgery. By CTV, the average distance from B1a to

Table 1. Values of the heights of B1a, B1m, C points above the ground. Distance between B1m, B1a and C points on 22 healthy subjects (in centimeters, single values, means±standard deviation).

	Height from ground			Distance between points	
	B1m	B1a	C	B1 a-m	B1a-C
	19	23	30	4	7
	22	26	32	4	6
	18	22	27	4	5
	19	23	30	4	7
	19	24	29	5	5
	20	22	28	2	6
	22	27	32	5	5
	22	25.5	30	4	4.5
	20	26	29	6	3
	21	28	31	7	3
	16	19.5	26	4	6.5
	20	28	31	8	3
	19	22.5	27.5	4	5
	21	21	30	0	9
	21	24.5	30	4	5.5
	19	22	28	3	6
	20	23.5	30	4	6.5
	24	29	34.5	5	5.5
	23	23	33	0	10
	25	28	32	3	4
	22	27.5	32.5	6	5
	22	26	33	4	7
Mean SD	20.64±2.06	24.59±2.65	30.25±2.16	3.95±1.87	5.66±1.76

SD, standard deviation.

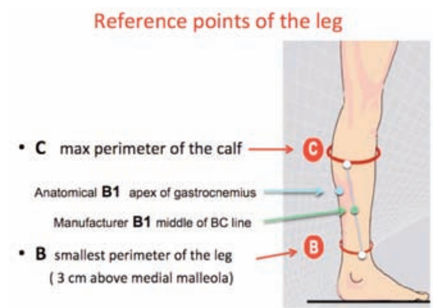

Figure 1. The main reference points of the leg commonly used to measure the interface pressure of a compression device.

Figure 2. Study of the anatomical landmarks of the reference points by 3D reconstruction with multi-slice computed tomography. Arrow shows the apex of the medial gastrocnemius muscle (B1a). MG, medial gastrocnemius muscle; Sol, soleus muscle; B1m, half distance measured between C and B.

Figure 3. Clinical assessment of the B1 point at the apex of the calf.

B1m was 3.6 cm (SD 1.63), average distance from B1a to C was 9.3 cm (SD 1.69). There was a significant correlation with tibial length (r=0.4, Table 2).

A comparison between the two measurement methods shows: i) there was a significant difference in the distance from the C point to the ground between the two measurement methods. The C point required repeated measurements and so appears to be difficult to locate clinically; ii) the *manufacturer's* B1 point is in the middle of the BC line and is not easy to locate; iii) the *anatomical* B1 point is the easiest to identify in clinical practice because it is located at the apex of the medial gastrocnemius muscle. As a result, it is easy to assess clinically and, if necessary, to verify by ultrasound. It is also the most reproducible; iv) the distance between the *anatomical* B1 and the *manufacturer's* B1 points are closer than the *anatomical* B1 and C points according to either calculation method.

Calculation of stiffness

Calculation of the median stiffness index on 11 legs with a Rosidal K™ (Lohmann & Rauscher, Table 3) shows that the SSI and the DSI were very similar at the B1a and C points; this is considered *stiff*. Median SSI was 14 mmHg at B1 *vs* 19 mmHg at C. Median DFSI was 29 mmHg at B1 *vs* 31 mmHg at C. Stiffness index measurement on 12 legs with a Coban™2 (3M™) (Table 4) also shows that SSI and DSI were very close at the B1a and C points; they are also considered *stiff*. Median SSI was 13.7 mmHg at B1 *vs* 14.3 mmHg at C. Median DSI was 26 mmHg at B1 *vs* 25.6 mmHg at C. Wherever the calculation of the stiffness is performed, the values at the C point and the *anatomical* B1 points were very close for both compression devices.

Table 2. Distances between the C point and B1a, B and B1m points. Distance B1a to B1m and the tibial length measured in centimeters measured on the 3D model of 19 legs prior to varicose vein surgery with OsiriX software (Pixmeo company, www.osirix.foundation.com).

	Tibial length	Distance between points			
		C-B1a	C-B	C-B1m	B1a-m
	33	9	22	11	2
	46	13	36	18	5
	46	12.8	34.4	17.2	4.4
	34	8.3	22.7	11.35	3.05
	36	9	23.2	11.6	2.6
	39	10.7	24.8	12.4	1.7
	38	7.8	21.3	10.65	2.85
	37	10.4	23	11.5	1.1
	39	9.4	27	13.5	4.1
	37	8.5	25.4	12.7	4.2
	38	8.5	26	13	4.5
	35	7.1	25.7	12.85	5.75
	36	10.8	24.4	12.2	1.4
	34.6	7.5	20.8	10.4	2.9
	43.6	8.3	26	13	4.7
	32.8	7.3	19.5	9.75	2.45
	39	9	31	15.5	6.5
	45.6	8.2	29	14.5	6.3
	40	10.2	25.2	12.6	2.4
Average	38.4	9.3	25.7	12.8	3.6
SD	4.21	1.69	4.37	2.18	1.63

SD, standard deviation.

Table 3. Interface pressure (mmHg) at B1 and C points under a Rosidal K (Lohman & Rauscher) bandage (11 legs).

	B1 point			C point		
	Rest	Contr	Stand	Rest	Contr	Stand
Average	41.4	74.5	58.3	36	61.5	51.5
SD	4.4	15	11.4	9.4	24	14.3
Median	41	70	55	35	67	54

Rest, at rest; Contr, with dorsiflexion; Stand, standing; SD, standard deviation.

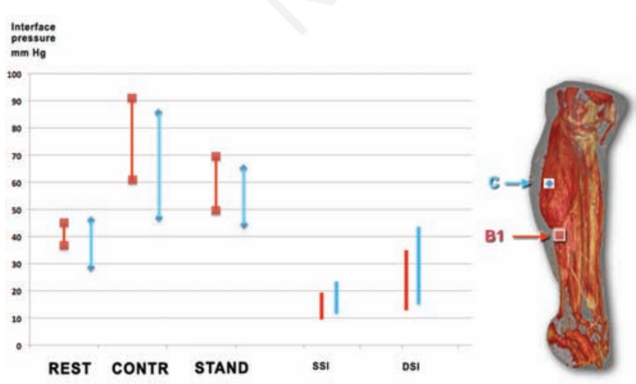

Figure 4. Pressures at rest, with dorsiflexions, during standing and stiffness indices under a Rosidal K (Lohman & Rauscher) on 11 legs. Ranges of 95% confidence interval. Rest, at rest; Contr, with dorsiflexion; Stand, standing; SSI, static stiffness index; DSI, dorsiflexion stiffness index.

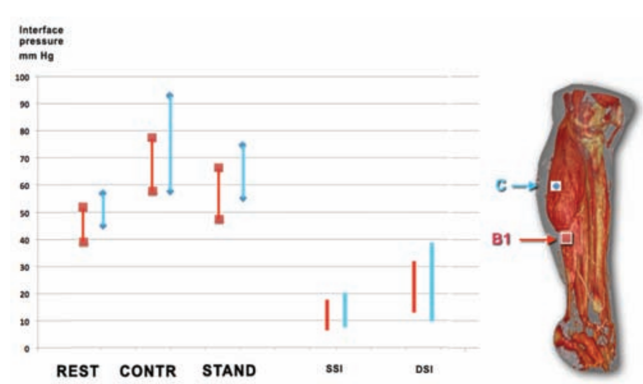

Figure 5. Pressures at rest, with dorsiflexions, during standing and stiffness indices under Coban™2 (3M™) on 12 legs. Ranges of 95% confidence interval. Rest, at rest; Contr, with dorsiflexion; Stand, standing; SSI, static stiffness index; DSI, dorsiflexion stiffness index.

Table 4. Interface pressure (mmHg) in B1 and C points under a Coban™2 bandage (12 legs).

	B1 point			C point		
	Rest	Contr	Stand	Rest	Contr	Stand
Average	43.3	70.9	57.6	43.9	68.8	58.4
SD	5.4	13.1	10.2	10.8	21.8	13.8
Median	42	68	55.7	45.7	71.3	60

Rest, at rest; Contr, with dorsiflexion; Stand, standing; SD, standard deviation.

Discussion

The distance between the C and *anatomical* B1 points was found to be significantly different by clinical and CT measurement (average 9.3 *vs* 5.6 cm; P<0.1). The possible explanation for this result could be the different position of the subjects, supine when submitted to CT and standing during the clinical examination. In fact, the C point varies according to positioning due to isometric contraction, lying or standing.

Conclusions

The C point is difficult to locate in practice. The *anatomical* B1 point is the most reliable point from a practical point of view, and is easier to use. The underlying anatomy is the Soleus muscle.

Stiffness at the *anatomical* B1 point seems adequate sufficient to assess stiffness of a medical device *in vivo*.

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