ARCHIVES OF SURGERY

February 1975

Type of Compression for Reducing Venous Stasis

A Study of Lower Extremities During Inactive Recumbency

Bernard Sigel, MD; Annette L. Edelstein; Lane Savitch; James H. Hasty, PhD; W. Robert Felix, Jr., MD

JAMA & ARCHIVES JOURNALS
American Medical Association

Type of Compression for Reducing Venous Stasis

A Study of Lower Extremities During Inactive Recumbency

Bernard Sigel, MD; Annette L. Edelstein; Lane Savitch;
James H. Hasty, PhD; W. Robert Felix, Jr., MD

Determination of the optimal compression to reduce venous stasis was studied in terms of the amount of pressure and manner of application (graded or uniform pressure). Both lower extremities of seven inactive recumbent subjects were tested using transcutaneous Doppler ultrasonic measurement of femoral vein blood flow velocity. Optimal compression was defined as the externally applied pressure that produced the greatest increase in femoral vein flow velocity consistent with safety and the practicality of hospital use of elastic stockings. Optimal compression for elastic stockings to be used by hospitalized patients who spend substantial time in bed should be 18 to 8 mm Hg (ankle to midthigh). At this compression, average femoral vein blood flow velocity is increased to 138.4% of base line. Gradient compression at this level was found to produce a greater femoral vein flow velocity than the same amount of compression distributed uniformly over the lower extremity.

We have previously reported evidence that elastic stocking compression during inactive recumbency produced an increased venous flow velocity and decreased venous pooling in lower extremities.[1] An important consideration in applying this to the prophylaxis of venous thrombosis in bedridden inactive patients is the manner in which compression should be applied. Specifically, we were interested in determining how much compression should be exerted by elastic stockings and whether compression should be applied as a gradient or uniformly to the lower extremity.

The importance of the degree of pressure to be exerted by compression is emphasized by the recent reports in the literature that indicate that, with progressive increases in compression, there is a diminution of circulation in lower limbs.[2,3] The clinical hazards for this are obvious, particularly in patients with preexisting arterial or venous disease.

In order to determine what might be the optimal compression levels for elastic stockings, we conducted a series of experiments in which body position resembled that of inactive bedridden patients in hospital. We defined optimal compression as the amount of externally applied pressure that produced the greatest increase in femoral vein flow velocity consistent with safety and the practicality of hospital use of elastic stockings. In terms of safety, optimal compression would be considered not only by its relation to maximum femoral vein velocity but also by its relation to decreasing velocity seen with increasing levels of external compression.

Our approach first was to determine optimal pressure using gradient compression. Then, we compared the effect of this gradient compression to the same average amount of compression distributed uniformly over the lower extremity.

METHOD

Human volunteers, fully informed in respect to the purpose and methods of the experiments, were the subjects. There were five women and two men, 22 to 60 years of age. All subjects were considered to have normal venous systems, except one with a history of thrombophlebitis.

All subjects were placed supine on an examining table that could be tilted to a foot-down position. Common femoral vein flow velocity in a lower extremity to be compressed was measured

Accepted for publication Aug 9, 1974.

From the Department of Surgery, Medical College of Pennsylvania (Drs. Sigel and Hasty, Ms. Edelstein, and Mr. Savitch) and the Veterans Administration Hospital (Dr. Felix), Philadelphia.

Reprint requests to Medical College of Pennsylvania, 3300 Henry Ave, Philadelphia, PA 19129 (Dr. Sigel).

transcutaneously by Doppler ultrasound blood flow velocity detectors using the same technique as described in our previous report.[1] Respiratory excursions were measured by a mercury-in-rubber strain gauge applied to the chest.

The device to compress the lower extremity was a five-chambered vinyl pneumatic sleeve. This sleeve extended from the ankle to the midthigh, and pressure within each chamber could be individually regulated. When in place, the five chambers encased the following regions of the lower extremity: ankle, calf, popliteal region, lower part of the thigh, and midthigh.

Following application of transducers, base line recordings of flow and respiration were made with the subject at tilt 0 degrees (parallel to floor).

Analysis of Gradient Compression Experiment

Six subjects were studied according to the protocol outlined in Table 1.

The three compression levels used were selected on the basis of ranges employed by commercial producers of elastic stockings intended for hospital use. In the first five of the 12 tests, we used a total of six compression levels. The additional levels were 14 to 2, 22 to 8, and 30 to 12 mm Hg. We abandoned the first two levels because the intermediate levels appeared to provide adequate data and we were interested in shortening the test to make the subjects more comfortable. We abandoned the 30 to 12 mm Hg gradient because of possible adverse effects observed (see "Results" section).

The amount of compression is expressed as the amount of pressure in each of the five chambers of the vinyl pneumatic sleeve. The first and highest values are for the ankle. The remaining pressures are in sequence for the calf, popliteal, lower part of the thigh, and midthigh. The average pressure of compression was derived by considering the proportion of surface area of the lower extremity covered by each chamber of the pneumatic sleeve. Figure 1 is a schematic representation of the experimental system employed.

Because of the tilting, problems were often encountered with displacement of the femoral vein transducer. In these instances, there was a noticeable diminution of the signal and failure to attain the same level of recording when the subject was returned to the horizontal position. Experience with externally measured femoral vein flow velocity using ultrasound has shown that in subjects undergoing no change in body position, the ultrasound signal at up to three hours was within 15% of the original base line levels.[1] Therefore, in the present experiments if the restored first base line was more than 15% below the original signal, we assumed that the transducer had become displaced and considered the data invalid.

During down-tilt, the subject placed the foot not being compressed against a board. Thus, the extremity being examined was non-weight bearing. For each subject, valid experiments were obtained on the right and left extremities (total of 12 studies).

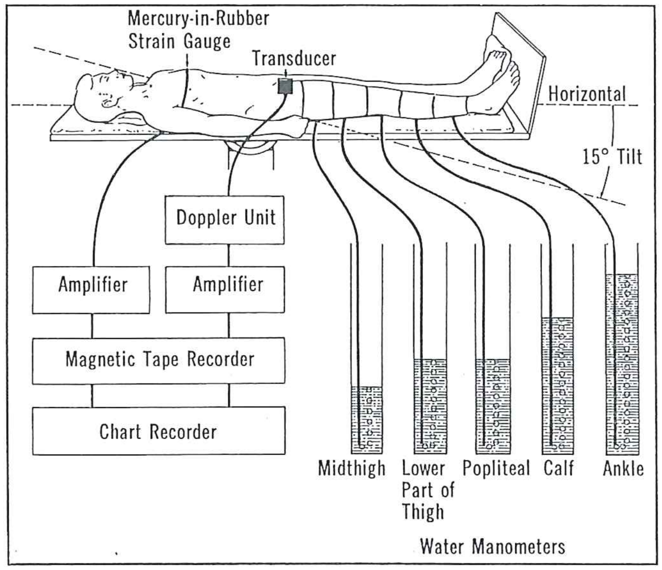

Fig 1.—Experimental system. Each pneumatic chamber is monitored independently.

Gradient Versus Uniform Compression Experiment

A second experiment was conducted in four subjects to evaluate the effectiveness of utilizing a gradient of pressures in the five chambers of the sleeve as compared to applying the same pressure (as determined by averaging the gradient of pressures based on the surface area covered by each chamber of the gradient) in all of the five chambers of the pneumatic sleeve. The experimental protocol followed was the same as that described previously with the exception that only two compression procedures were employed. After base line recording, a uniform pressure of 11 mm Hg was applied to all levels of the lower extremity. This was followed by a pressure gradient of 18 to 8 mm Hg.

RESULTS

The level of femoral vein flow velocity during the last five minutes of each pressure period was averaged. The average for that period represents the flow measurement used in analysis. All flow velocity expressions are in terms of a reference base line that is normalized or considered as 100%.

There was great variability in the responses to compres-

Table 1.—Protocol for Performing Gradient Compression Experiment

Period	Position of Subject	Amount of Compression, mm Hg: Gradient Pressure	Average Pressure	Duration, min
First base line	Horizontal	None	...	5
Second base line	15° foot-down tilt	None	...	5
Compression 1	15° foot-down tilt	10, 6, 4, 4, 2	5	15
Compression 2	15° foot-down tilt	18, 14, 8, 10, 8	11	15
Compression 3	15° foot-down tilt	26, 22, 14, 16, 12	17	15
Second base line restored	15° foot-down tilt	None	...	5
First base line restored	Horizontal	None	...	5

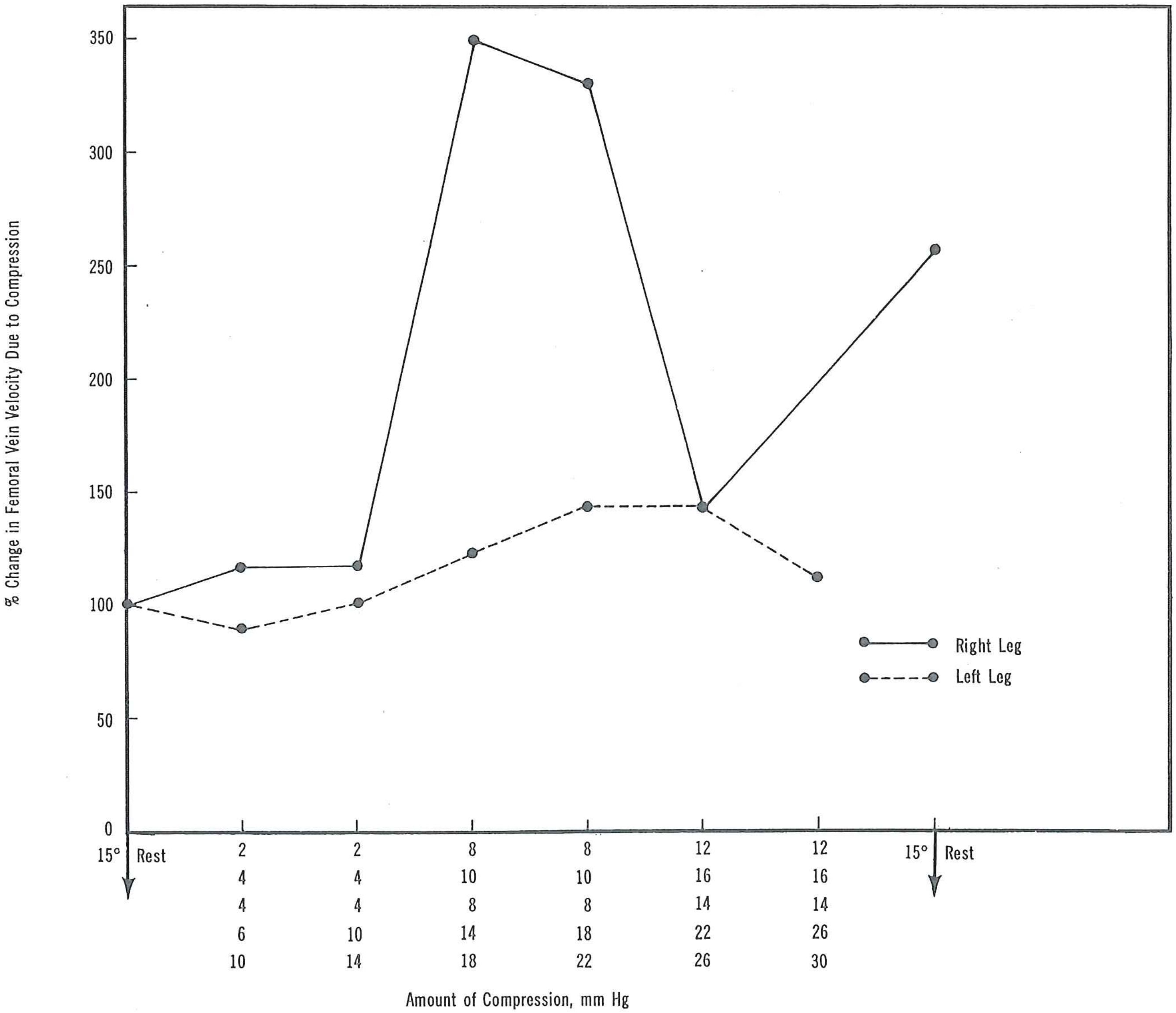

Fig 2.—Femoral vein flow velocity in response to varying graded compression in subject 2. Note that right leg compression pressure greater than 18 to 8 mm Hg produced decrease in femoral vein flow velocity. In left leg, gradient compression of 30 to 12 mm Hg produced decline in flow velocity.

sion between the tests. This variability was observed not only between subjects, but also between right and left legs of the same subject. As a consequence, we used geometric means to average our results in order to reduce the effect of higher percentage increases. For purposes of the statistical analysis, it appeared appropriate to consider subjects rather than extremities. Consequently, a geometric mean of the changes seen for the right and left side for each subject is present. In determining change due to compression, all values are expressed in terms of the second or foot-down tilt base line, which represents 100%.

Analysis of Gradient Compression Experiment

Table 2 shows the results of the 12 experiments in the six subjects. Fifteen-degree foot-down tilt produced a decrease in blood flow velocity to 61.3% of the first or horizontal base line. In terms of the foot-down tilt base line, the first compression was associated with a slight increase in flow velocity (108.4%). The second compression produced a further increase (138.4%). Third compression produced an average increase that was greater than that during second compression (151.7%). However, in subject 2 (right leg), femoral vein flow velocity was less than that during second compression, although it was increased over base line (Fig 2). In this same subject, during testing on the left leg, we used a compression gradient of 30, 26, 14, 16, and 12 mm Hg. This was early in our experience, and we routinely used this compression pressure in all experiments to this point. At this level, we observed a decrease in venous flow velocity, although velocity was still above base line. Because of these experiences with this subject, we abandoned the 30 to 12 mm Hg compression level.

Table 2.—Changes in Femoral Vein Flow Velocity With Compression

Subject No.	Base Line 2/ Base Line 1, %			First Compression, %*			Second Compression, %*			Third Compression, %*			Restored Base Line 2, %†			Restored Base Line 1, %†		
	R	L	Mg	R	L	Mg	R	L	Mg	R	L	Mg	R	L	Mg	R	L	Mg
1	64.7	80.0	71.9	90.9	91.7	91.3	118.2	100.0	108.7	127.3	125.0	126.1	90.9	66.7	77.9	94.1	146.7	117.5
2	34.3	64.3	47.0	116.7	88.9	101.9	350.0	122.2	206.8	141.7	144.4	143.0	266.7	...	266.7	102.9	114.0	108.3
3	69.2	90.0	78.9	100.0	122.2	110.5	100.0	188.9	137.4	122.2	244.4	172.8	100.0	111.1	105.4	131.0	140.0	135.4
4	27.3	62.1	41.2	150.0	138.9	144.3	216.7	155.6	183.6	283.3	200.0	238.0	150.0	150.0	150.0	90.9	331.0	173.5
5	81.0	71.4	76.0	111.8	100.0	105.7	117.7	95.0	105.7	129.4	90.0	107.9	111.8	75.0	91.6	105.0	103.6	104.3
6	60.9	66.7	63.7	107.1	100.0	103.5	114.3	120.0	117.1	128.6	180.0	152.1	135.7	100.0	116.5	143.5	100.0	119.8
Geometric mean (Mg)			61.3			108.4			138.4			151.7			123.3			124.6

* Percent is calculated in terms of second base line (15° foot-down tilt).
† Percent is calculated in terms of initial value for each base line.

Table 3.—Femoral Vein Flow Velocity With Uniform and Gradient Compression

Subject No.	Base Line 2/ Base Line 1, %			Uniform Compression, %*			Gradient Compression, %*			Restored Base Line 2, %†			Restored Base Line 1, %†		
	R	L	Mg	R	L	Mg	R	L	Mg	R	L	Mg	R	L	Mg
1	80.0	53.8	65.6	108.3	92.9	100.3	116.7	100.0	108.0	100.0	92.9	96.4	93.3	84.6	88.8
4	57.1	67.9	62.3	95.0	94.7	94.9	120.0	115.8	117.9	115.0	105.3	110.0	100.0	117.9	108.6
5	68.8	81.8	75.0	100.0	100.0	100.0	181.8	138.9	158.9	118.2	111.1	114.6	118.8	127.3	123.0
7	50.0	53.3	51.6	109.1	218.8	154.5	118.2	243.8	169.8	136.4	118.8	127.3	122.7	190.0	152.7
Geometric mean (Mg)			63.1			110.1			136.1			111.5			116.0

* Percent is calculated in terms of second base line (15° foot-down tilt). Uniform compression: 11, 11, 11, 11, 11 mm Hg; gradient compression: 18, 14, 8, 10, 8 mm Hg.
† Percent is calculated in terms of initial value for each base line.

The average flow during the restored second and first base lines (expressed as a percent of the initial base line levels) was greater than the initial base lines, reflecting a persistence of compression effect. We observed similar results in our previous study.[1]

Statistical analysis first was directed to compare the geometric mean of each compression effect with base line (100%) by means of a paired t test. The first compression mean did not differ significantly from base line. Second and third compressions were significantly above base line ($P < .05$). Next, the effects of the three compressions were compared among themselves, using an analysis of variance for repeated measurements in the same subjects.[4] This disclosed that both second and third compressions produced an increase in femoral vein flow velocity that was significantly greater than the effect of first compression ($P < .05$). However, there was no statistically significant difference in the effect of third compression compared to second compression.

Based on this analysis, we concluded that graded lower extremity pressure of 18 mm Hg at the ankle to 8 mm Hg at the midthigh level is the optimal pressure to increase femoral vein flow velocity in subjects inclined to a 15° foot-down tilt. While compression at a higher level (26 to 12 mm Hg) produced a higher average blood flow velocity, this was not significantly greater than the previous level and was associated in one subject with a decline in flow velocity.

Gradient Versus Uniform Compression Experiment

The results of the experiment to examine the difference between the optimal gradient compression and the comparable pressure exerted as uniform compression demonstrated generally small but consistent increases in venous blood velocity with gradient compression. Table 3 shows that in all eight extremities studied, gradient compression (18, 14, 8, 10, 8 mm Hg) produced a higher femoral vein flow velocity than uniform compression (11 mm Hg). This difference was statistically significant ($P < .05$) (paired t test using a one-tailed analysis of data).

COMMENT

In this study, the optimal pressure gradient to compress lower extremities has been estimated in terms of effect on femoral vein flow velocity. This is based on the assumption that such a measure is a valid means of determining to what extent lower limb compression, as produced by elastic stockings, can overcome venous stasis.

Optimal compression, as we have defined it, produced less than maximal femoral flow velocity in most of the subjects tested. Nevertheless, we considered this lower level of compression as optimal because its effect on the average was not statistically different from that of the next higher level and out of consideration of patient safety. In one of the six subjects tested in this part of the experiment, maximal femoral vein flow velocity was reached at the 18 to 8 mm Hg compression gradient and greater compression levels produced a decline in flow velocity, although this was still higher than base line values. We considered that gradient compression of 26 to 12 mm Hg or greater might be undesirable for recumbent subjects and selected, therefore, a compression level of 18 to 8 mm Hg as optimal for general hospital use.

In conducting these experiments, our intent has been to establish laboratory conditions that resemble the hospital ambience for most patients considered at risk for venous thromboembolism because of their inactivity and extended confinement to bed. Based on this consideration, we selected a 15° foot-down tilt for our subject experiments. The body was kept straight (not flexed at the hips) to diminish transducer placement problems over the femoral vein.

Body position is an important consideration because it affects the pressure within the lower extremity veins and, thus, the amount of compression needed to produce maximal venous flow velocity. From physiological considerations, compression levels higher than 18 to 8 mm Hg would be expected to be more effective at inclinations greater than 15°. As the lower limbs attain positions of greater dependency, the transmural pressure in the deep veins of lower extremities increases.[5] Thus, more compression would be required to prevent distention of veins resulting from the added hydrostatic pressure as dependency of the lower limbs is increased.

Conversely, when the lower limbs of a supine subject are elevated, less compression may be needed to increase venous velocity. In a previous study,[1] we found that femoral vein blood velocity measured by transcutaneous Doppler ultrasound instrumentation increased by about 30% with a 10 degree foot incline above horizontal. Under such circumstances, elastic stockings exerting an 18 to 8 mm Hg gradient probably would have little further effect on increasing blood velocity.

The selection of the most appropriate pressure gradient for elastic stockings worn by hospitalized patients should be tempered by these considerations. Compression levels designed to produce optimal flow velocity in dependency may exert an undesired effect in a supine position. Since hospitalized patients are in bed a large portion of the time, optimal compression pressures should be reckoned on the basis of the usual position assumed by such patients. Stockings that are optimal during dependency would tend to overcompress when the subject is supine; hence, it would not be indicated to utilize this higher compression level for general hospital use. Stockings that are optimal at 15° foot-down tilt (18 to 8 mm Hg) probably undercompress when the patient is in a more erect position; however, with respect to universal hospital use, this would be the safer compromise.

For these reasons, we conclude that the 18 to 8 mm Hg gradient is best for general use on hospitalized patients who are inactive and in bed for substantial time periods.

Although gradient compression has been employed in stocking application in most instances, its effect in comparison to nongradient has not been demonstrated in terms of venous flow velocity. The experiment reported demonstrates that gradient compression at the recommended level in recumbent subjects is more effective than the equivalent compression applied uniformly. This provides quantitative confirmation for the appropriateness of using compression gradients in elastic stockings to reduce venous stasis.

CONCLUSIONS

1. At a body position considered most characteristic of hospitalized subjects, a 15° foot-down tilt, the recommended ankle to midthigh pressure gradient for elastic stockings is 18 to 8 mm Hg. At this compression, average femoral vein blood flow velocity increased to 138.4% of base line. Femoral vein blood flow velocity was increased further by compression at a 26 to 12 mm Hg gradient. However, at this pressure gradient, the increase in flow velocity was not significantly greater and, in one instance, was decreased compared to the 18 to 8 mm Hg gradient.

2. While the 18 to 8 mm Hg gradient may be a less effective compression when the limbs are in a more dependent position, we considered this to be the appropriate gradient for general use in hospitalized patients who are confined to bed for substantial time periods.

3. The application of a gradient compression (18 to 8 mm Hg) increased venous velocity to a higher level than the application of a uniform pressure equal to the weighted average of pressure exerted by this gradient. This tended to confirm the appropriateness of using gradient compression stockings to reduce venous stasis.

This investigation was supported by National Institutes of Health grant HL11774; a grant from the Kendall Company, Barrington, Ill; Veterans Administration Part I Funds; and the John A. Hartford Foundation.

References

1. Sigel B, Edelstein AL, Felix WR Jr, et al: Compression of the deep venous system of the lower leg during inactive recumbency. *Arch Surg* 106:38-43, 1973.

2. Spiro M, Roberts VC, Richards JB: Effects of externally applied pressure on femoral vein blood flow. *Br Med J* 1:719-723, 1970.

3. Sabri S, Roberts VC, Cotton LT: Effects of externally applied pressure on the haemodynamics of the lower limb. *Br Med J* 3:503-508, 1971.

4. Winer BJ: *Statistical Principles in Experimental Design.* New York, McGraw-Hill Book Co Inc, 1962.

5. Folkow B, Neil E: *Circulation.* New York, Oxford University Press, 1971.