

Superimposed Elastic Stockings: Pressure Measurements

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BACKGROUND High-compression stockings over 40 mmHg are often difficult or even impossible to apply. A specific technique is frequently used to overcome this problem: a high-compression stocking is replaced by two or even three lower compression stockings that are applied on top of each other, thereby reducing the effort of application. To our knowledge, however, no study concerning therapeutic stockings has demonstrated that the forces exerted by two or three superimposed stockings are additive.

OBJECTIVE The objective was to evaluate if the pressures exerted by two or three superimposed elastic stockings are additive.

MATERIAL AND METHODS A series of measurements was performed in vitro using an apparatus fitted with a pressure sensor on four different premade elastic stockings applied separately and then superimposed. The actual pressure measurement obtained with superimposed stockings was compared to arithmetic sum of the pressures produced by each of the stockings used.

RESULTS The pressures produced by superimposed stockings are adequately predicted from the pressure given by each of the stockings used in the superposition, with correlation coefficients higher than 0.9.

CONCLUSION Under our experimental conditions, the superimposed elastic stocking pressures additivity hypothesis is confirmed. In vivo studies should be conducted to confirm those results.

The authors have indicated no significant interest with commercial supporters.

Compression therapy with elastic stocking constitutes the basic treatment for chronic venous disorders of the legs,^{1,2} as recently confirmed by inclusion of compression therapy in the clinical severity score of the CEAP classification.³ The need for using elastic stockings exerting a high pressure at the ankle has been recently demonstrated.⁴ Application of high-pressure stockings, however, is often difficult or even impossible for many patients. It has therefore been proposed to apply two less compressive stockings on top of each other to facilitate application and to obtain high compression forces, although it has not been demonstrated whether or not these forces are additive⁵⁻⁷ (e.g., two superimposed elastic stockings, each exerting a pressure of 20 mmHg at the ankle, is equivalent to application of a single 40 mmHg stocking).⁸ The hypothesis of an additive effect

of the pressures of superimposed stockings therefore needs to be assessed.

The principle of this study was to measure the pressures resulting from two or even three superimposed elastic stockings. These measured pressures were then compared to the calculated superimposed pressure (arithmetic sum of the pressures exerted by each individual stocking).

Materials and Methods

Material

Elastic stockings were premade stockings (Venoflex, Thuasne, France), divided into four different pressure groups identified by the A, B, C, and D code to facilitate detection during manipulations. Stockings identified as A exert a pressure of approximately

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10 mmHg at the ankle, stockings identified as B exert a pressure of approximately 15 mmHg, stockings identified as C exert a pressure of approximately 20 mmHg, and stockings identified as D exert a pressure of approximately 30 mmHg. The four types of stockings had the same size, i.e., adjusted to a leg with an ankle circumference of 24 cm.

The measuring device is based on a pressure sensor (Thuasne Research and Development Department), composed of a metal cylinder with an aperture at its superior part and an air circuit supplied by a small electric motor (Figure 1). The cylinder, with a constant circumference of 24 cm, is taken as an anatomical model of the ankle on which the smallest circumference stocking is placed (Figure 2). The aperture is connected to the air circuit and a manometer. The maximum pressure measured by this manometer is 60 mmHg.

When one stocking or combination of stockings is placed on the cylinder, a depression forms over the aperture due to the tension exerted by the elastic



Figure 1. Photograph of the apparatus.

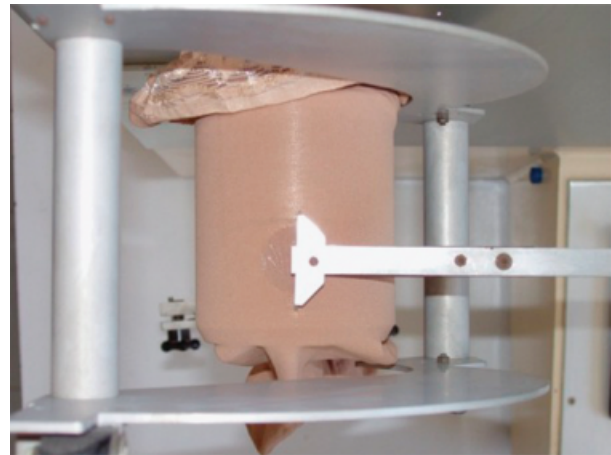


Figure 2. Cylinder and stocking in place (view from the top).

tissue. Air is injected into the cylinder at a certain pressure to eliminate this depression formed by the stocking. A contact transducer identifies elimination of the depression, and the air injection is stopped immediately. A direct reading system then displays the pressure (mmHg) exerted by the stocking or combination of superimposed elastic stockings.

Methods

A stocking was taken at random from each of the four groups. Pressure measurements were performed in the following order: determination of the pressure exerted by each individual stocking and then determination of the pressure exerted by two and three superimposed stockings.

Determination of the Pressure Exerted by Each Individual Stocking Before each measurement, the zone corresponding to the aperture of the cylinder was identified so that it was always located in the same position for each measurement. Stocking A was applied onto the cylinder. The stocking pressure (pr) was then measured. Stocking A was removed for 10 minutes to allow the elastic material to reach a new steady state. This procedure was repeated 30 times for each Stocking A, B, C and D. The mean value was calculated. The pr for Stocking A (prA), the pr for Stocking B (prB), the pr for Stocking C (prC), and the pr for Stocking D (prD) were therefore determined.

Determination of the Pressure Exerted by the Various Combinations of Superimposed Stockings The stockings were placed one over the other onto the cylinder, exactly superimposing the previously identified measuring zones over the aperture. Superimposition of the stockings was facilitated by applying the highest compression stocking first. The pressure exerted was measured after an interval of 10 minutes. The stockings were then removed from the apparatus and allowed to rest for 10 minutes, before being re-used for other measurements. This procedure was repeated 30 times for each combination of two superimposed stockings (B + A, C + A, D + A, C + B, D + B, D + C) and then for the three superimposed stockings (C + B + A, D + B + A). The mean values were calculated. The pr(B + A), pr(C + A), pr(D + A), pr(C + B), pr(D + B), pr(D + C), pr(C + B + A), and pr(D + B + A) were therefore determined.

Theoretical Pressures of the Various Combinations of Superimposed Stockings The theoretical pressure produced by the superimposed stockings was calculated as the arithmetic sum of each stocking pressure. For example: the theoretical pressure of the A + B superimposed stockings is equal to prA + prB.

Comparison of Measured and Theoretical Pressures The comparison between theoretical and measured pressures was performed through a regression analysis, with the calculation of the determination coefficient as an index of the quality of the prediction by the additivity model.

Results

Measured pressures of each individual Stocking A, B, C, and D code are shown in Table 1. The results of 30 successive measurements are shown in Appendix 1.

Measured pressures of the various superimposed stockings combinations are shown in Table 2. The results of 30 successive measurements are shown in Appendix 1.

Theoretical pressures of superimposed stockings combination are shown in Table 3. This calculated pressure is the arithmetic sum of the pressure of each stocking.

TABLE 1. Measured Pressures (mmHg) for Stockings A, B, C, and D

| Stocking code | Measured pressures (mean ± SD) |
|---------------|--------------------------------|
| A | 10.4 ± 0.8 |
| B | 15.4 ± 0.9 |
| C | 22.6 ± 0.9 |
| D | 31.6 ± 0.8 |

TABLE 2. Measured Pressures (mmHg) of Superimposed Stocking Combinations

| Superimposed stocking combinations | Measured pressures (mean ± SD) |
|------------------------------------|--------------------------------|
| B + A | 24.2 ± 1.4 |
| C + A | 32.7 ± 1.3 |
| D + A | 42.4 ± 1 |
| C + B | 38.4 ± 0.9 |
| D + B | 46.1 ± 0.9 |
| D + C | 55.5 ± 0.6 |
| C + B + A | 50.2 ± 0.7 |
| D + B + A | 54.4 ± 0.7 |

Comparison of Measured and Theoretical Pressures

Figure 3 illustrates the regression of measured pressures compared to the theoretical ones deduced from the additivity model. A linear regression with the equation $y = 0.9727x + 1.3083$ gives a very high correlation with a determination coefficient $r^2 = 0.9782$. This curve is not statistically significant from the equality line $y = x$.

TABLE 3. Theoretical Pressures (mmHg) of Superimposed Stocking Combinations (Arithmetic Sum of Each Stocking Measured Pressure)

| Superimposed stockings combinations | Theoretical pressures (mean ± SD) |
|-------------------------------------|-----------------------------------|
| prB + prA | 25.8 ± 1.2 |
| prC + prA | 33 ± 1.2 |
| prD + prA | 42 ± 1.1 |
| prC + prB | 38 ± 1.3 |
| prB + prD | 47 ± 1.2 |
| prD + prC | 54.2 ± 1.1 |
| prC + prB + prA | 48.4 ± 1.5 |
| prD + prB + prA | 57.4 ± 1.4 |

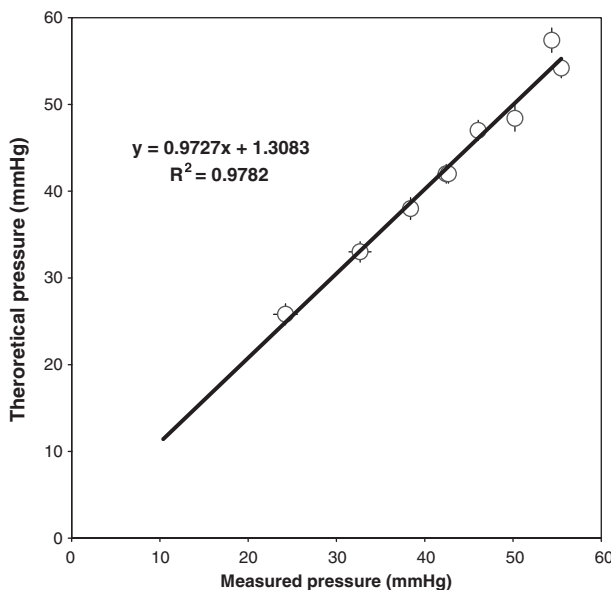


Figure 3. Comparison of theoretical versus measured pressures.

Discussion

This study consisted of measuring the pressure exerted by various combinations of superimposed elastic stockings. Under our experimental conditions, the pressure exerted by two or three superimposed elastic stockings is equal to the sum of the pressures exerted by each of these stockings.

This study did not, however, evaluate stockings exerting a pressure less than 10 mmHg and greater than 32 mmHg or stockings with a higher resistance coefficient.⁸ The apparatus could also have been designed to test several stocking sizes. We used standard stockings with an intermediate ankle circumference to obtain more homogeneous results. Thirty measurements were performed on Stockings A, B, C, and D and on the various combinations. It had been impossible to measure pressure above 60 mmHg. A more complete study would have required a full-time engineer working for more than 10 days, which did not appear to be justified.

When stockings are superimposed in routine clinical practice, the stocking exerting the lowest compression is applied first and the stocking exerting the highest

compression is simply slipped over the first stocking. In this study, the stockings were applied onto the cylinder in the opposite order, because the manipulation is easier and more precise when the stocking exerting the highest compression is applied first. This method, however, should not modify the results.

A previous study used the Doppler technique⁹ to compare the arterial hemodynamic effects of *single* or *multiple* elastic stockings.¹⁰ This study concluded that the distal blood pressure measured by Doppler was decreased to the same degree by a single stocking as by superimposed stockings exerting the same dynamometric force. This *in vivo* study provided a real approach to the concept of additive pressure in the case of superimposed stockings and the present study confirms this concept.

Another study explored the reduction of edema by elastic stockings and concluded that the pressure exerted by several superimposed stockings was slightly greater than the sum of the pressures exerted by each individual stocking.⁸ Our findings are not in agreement with these conclusions. This 1985 study using a dynamometer established hysteresis curves for each stocking and each pair of superimposed stockings. The calculations also concluded on the addition of resistance coefficients (degree of stiffness). The apparatus used in the present study did not allow the construction of hysteresis curves or the calculation of this coefficient, whose characteristics were given again in a recent publication.¹¹

Two works have been performed with sensors *in vivo*: A survey on thromboprophylactic stockings using the Borgnis medical stocking tester has shown that the pressure was about twice as high with two thromboprophylactic stockings than with one.¹² The second one has used the Kikuhime tester to demonstrate its good reproducibility.¹³ Our study could have been conducted *in vivo*, requiring the use of pressure sensors placed under the stockings, but no sensor was available at our study time. It is probable that *in vivo* measurements

will show a higher variability of the results due to some degree of anatomical variation, but the additivity principle should be statistically verified in every case, as far as the stockings are well suited to the examined leg.

Further studies must therefore be conducted to refine these results. They should be conducted with other stockings and other pressures, using other apparatuses. They should be conducted possibly in vivo as was already started in 2005.¹⁴

Our results, however, already appear to be sufficient to justify the use of superimposed elastic stockings. High-compression elastic stockings are often difficult or even impossible to apply, but this problem can be overcome by applying two or even three lower-compression elastic stockings. Pressures of 40 or 60 mmHg can be achieved by superimposing two or three 20 mmHg stockings. This reduction of the effort of application is particularly useful in the treatment of leg ulcers^{5,6} and after venous surgery:⁷ high-compression stockings are worn during the day and removed at night. Only low-compression stockings are worn at night to keep the dressings in place. This technique is also useful to treat lymphedema, to maintain varicose veins dilatations during pregnancies, and to help older people to put on compression stockings. In an opposite way, compression forces can be increased as well by superimposing several stockings. It allows a reduction of lower limbs edema.¹⁵

Conclusion

Under our experimental conditions, the pressure exerted by several superimposed stockings is equal to the sum of the individual pressures of each stocking. The calculation of the superimposed pressure therefore corresponds to a simple addition. Further in vivo studies should be conducted to confirm those results in clinical conditions.

The principle of superimposed stockings allows the physician to modulate the pressure exerted as required. It facilitates application of high compression

by the patient, by reducing the problem of stocking insertion. Thereby, the efficacy and compliance of compressive therapy should be improved.

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Appendix 1

| | Results (mmHg) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ‡ | | | |
|-----------|----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|-----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30* | | | | |
| A | 12.0 | 9.0 | 10.9 | 10.8 | 11.6 | 10.8 | 9.9 | 9.8 | 10.9 | 11.5 | 10.9 | 11.2 | 9.4 | 11.0 | 10.8 | 9.6 | 9.4 | 10.1 | 9.8 | 10.6 | 9.5 | 11.1 | 9.6 | 10.6 | 11.1 | 11.0 | 9.3 | 9.2 | 9.8 | 10.8 | 10.4 | 0.8 | | |
| B | 15.9 | 14.1 | 15.9 | 16.8 | 15.3 | 14.1 | 16.4 | 15.4 | 16.5 | 16.7 | 16.8 | 15.3 | 14.7 | 13.8 | 15.1 | 15.4 | 16.1 | 14.7 | 16.5 | 14.1 | 15.3 | 16.2 | 15.5 | 15.1 | 15.4 | 13.9 | 15.5 | 15.6 | 14.1 | 14.7 | 15.4 | 0.9 | | |
| C | 22.0 | 22.6 | 23.7 | 23.3 | 21.4 | 21.3 | 24.1 | 23.2 | 22.2 | 23.2 | 22.4 | 22.7 | 23.5 | 22.3 | 23.6 | 22.9 | 23.3 | 21.1 | 23.6 | 21.7 | 23.2 | 21.7 | 21.6 | 21.4 | 21.1 | 23.3 | 22.5 | 23.3 | 23.0 | 22.7 | 22.6 | 0.9 | | |
| D | 31.9 | 31.2 | 30.5 | 33.1 | 30.9 | 31.1 | 32.4 | 32.6 | 31.3 | 31.3 | 31.1 | 32.1 | 32.5 | 31.4 | 31.6 | 31.4 | 31.9 | 31.3 | 31.4 | 30.9 | 31.5 | 32.3 | 32.5 | 32.0 | 32.6 | 31.5 | 31.4 | 32.6 | 30.3 | 30.2 | 31.6 | 0.8 | | |
| B + A | 26.2 | 25.3 | 22.3 | 26.2 | 22.7 | 23.8 | 25.3 | 25.6 | 25.9 | 25.5 | 23.0 | 22.3 | 23.0 | 23.1 | 24.1 | 26.5 | 24.2 | 23.1 | 25.6 | 26.2 | 23.8 | 23.7 | 23.7 | 22.3 | 22.9 | 23.2 | 23.3 | 24.9 | 23.7 | 25.7 | 24.2 | 1.4 | | |
| C + A | 33.5 | 32.5 | 33.3 | 31.7 | 31.7 | 33.8 | 33.2 | 30.5 | 33.4 | 30.5 | 33.7 | 32.8 | 33.4 | 31.8 | 33.5 | 31.1 | 33.7 | 30.0 | 32.3 | 33.7 | 33.6 | 33.9 | 33.8 | 34.1 | 32.3 | 32.2 | 29.8 | 33.5 | 33.0 | 33.9 | 32.7 | 33.0 | 1.3 | |
| D + A | 42.9 | 42.5 | 41.5 | 41.7 | 44.3 | 42.4 | 42.6 | 43.5 | 43.6 | 42.9 | 41.3 | 43.2 | 41.1 | 42.3 | 42.5 | 43.3 | 43.5 | 43.0 | 40.9 | 41.8 | 41.1 | 42.1 | 41.7 | 41.2 | 43.1 | 43.5 | 42.9 | 41.4 | 44.0 | 41.6 | 42.4 | 1.0 | | |
| C + B | 38.7 | 38.3 | 38.4 | 38.2 | 36.5 | 38.8 | 38.7 | 39.5 | 39.3 | 38.4 | 39.0 | 38.9 | 37.4 | 38.6 | 37.1 | 38.6 | 37.1 | 38.6 | 37.6 | 39.3 | 38.2 | 38.7 | 38.2 | 36.9 | 39.7 | 38.5 | 37.1 | 38.2 | 38.8 | 38.9 | 37.1 | 38.4 | 37.7 | 0.9 |
| D + B | 44.4 | 46.2 | 46.0 | 47.7 | 45.2 | 45.5 | 45.5 | 44.4 | 44.2 | 45.3 | 47.1 | 47.8 | 46.4 | 45.6 | 46.8 | 46.2 | 45.9 | 46.5 | 46.3 | 46.8 | 46.5 | 46.8 | 45.3 | 46.4 | 45.9 | 46.6 | 46.2 | 46.3 | 45.4 | 46.1 | 46.1 | 47.0 | 0.9 | |
| D + C | 55.3 | 54.7 | 55.2 | 56.2 | 54.6 | 56.1 | 55.9 | 55.0 | 54.7 | 56.0 | 55.7 | 56.2 | 56.0 | 55.3 | 55.6 | 56.3 | 55.0 | 55.0 | 56.3 | 56.2 | 55.9 | 55.9 | 55.3 | 54.7 | 55.1 | 56.1 | 55.0 | 55.2 | 55.0 | 55.5 | 54.3 | 0.6 | | |
| C + B + A | 49.8 | 49.0 | 50.0 | 49.7 | 49.6 | 49.8 | 50.8 | 49.7 | 51.1 | 50.1 | 49.8 | 50.8 | 51.0 | 49.9 | 49.7 | 49.8 | 49.8 | 51.3 | 50.9 | 50.7 | 51.4 | 49.8 | 50.8 | 51.1 | 49.6 | 50.7 | 49.8 | 50.8 | 49.2 | 50.5 | 50.2 | 48.3 | 0.7 | |
| D + B + A | 55.5 | 54.2 | 55.0 | 54.3 | 54.2 | 55.0 | 55.6 | 55.0 | 54.3 | 54.4 | 54.2 | 53.8 | 53.8 | 54.1 | 55.2 | 54.4 | 53.4 | 54.6 | 53.9 | 54.4 | 53.9 | 55.0 | 53.7 | 53.3 | 54.5 | 55.5 | 54.0 | 55.6 | 53.5 | 53.9 | 54.4 | 57.4 | 0.7 | |

*Measured pressures (mean).

†Theoretical pressures (mean).

‡SD.

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COMMENTARY

André Cornu-Thénard is a pioneer of the idea to put a compression stocking on top of another stocking. In fact multilayer compression has several practical advantages:

- The application is easier.
- One layer can stay on overnight, while the second layer is worn over it during daytime, when a higher compression pressure is needed to counteract gravity.
- There is not only an increase of the interface pressure, as nicely demonstrated in this study, but also a disproportionate increase in stiffness.

Several colleagues already use this principle successfully after surgery on varicose veins, endovenous therapy, or foam sclerotherapy, to achieve sufficient compression of the treated veins, which is not always easy, as for instance in the thigh region.

The concept has also been adopted by several companies offering a combination of two stockings for the treatment of venous leg ulcers. The first stocking is used as a “liner” with the main function to keep the ulcer dressing in place and to provide a gliding aid for the second stocking, that can be removed overnight. At least for small ulcers, and those of relatively short duration, good healing rates have been reported in comparison with conventional bandages.

Cornu-Thénard and coworkers have restored our belief in mathematics: $10 + 10 = 20$, $15 + 15 = 30$, and $30 + 10 = 40$. These simple additions are not valid when it comes to stiffness, which is another important parameter for the efficacy of a compression product. It is also not true for bandages, where the addition of several layers leads to a minor pressure increase, obviously depending on the width of the bandage.

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