Eur J Vasc Endovasc Surg **27**, 94–99 (2004)
doi: 10.1016/j.ejvs.2003.10.014, available online at http://www.sciencedirect.com on SCIENCE DIRECT

Multi-layer Compression: Comparison of Four Different Four-layer Bandage Systems Applied to the Leg

J. J. Dale,[1] C. V. Ruckley,[2*] B. Gibson,[3] D. Brown,[4] A. J. Lee[5] and R. J. Prescott[2]

[1]*Lothian Health Board, Edinburgh,* [2]*Department of Surgery, Faculty of Medicine, Edinburgh University, Edinburgh,* [3]*Falkirk and District Royal Infirmary, Westburn Avenue, Falkirk, Scotland,* [4]*Lothian Health Primary Care Trust, Edinburgh, and* [5]*Medical Statistics Unit, University of Edinburgh, Edinburgh, Scotland, UK*

Objective. *To compare performance of four commercial four-layer bandage systems when applied to the leg.*
Methods. *Four experienced bandagers applied each system: [Profore Regular (Smith and Nephew); Ultra-Four (Robinson); System 4 (Seton) and K Four (Parema)] to the same leg. Bandages were applied as single layers and as completed systems using standard techniques. For each application, 18 pressure measurements were taken using the Borgnis Medical Stocking Tester (MST) at three measuring points (ankle, gaiter and mid-calf) on medial and lateral aspects in three postures: (horizontal, standing and sitting).*
Results. *In all 2304 observations were made, 576 for each bandager, 576 for each bandaging system, 768 for each measuring point, 1152 for each aspect and 768 for each posture. The increase in pressure produced by each additional layer was 65–75% of the pressure of the same bandage when used as a single layer. There were significant differences in the final pressures achieved by the bandagers (means: 45–54 mmHg,* $p < 0.001$*) and between bandage systems (means: System 4: 46 mmHg, Profore: 47 mmHg, K Four: 52 mmHg, Ultra-Four: 54 mmHg;* $p = 0.005$*). The relationships between the final pressures achieved at each of the three measuring points, the three postures and the two aspects were not consistent among the bandage systems (*$p < 0.01$*).*
Conclusions. *When a bandage is applied as part of a multi-layered system it exerts approximately 70% of the pressure exerted when applied alone, thus challenging the commonly-held assumption that the final pressure achieved by a multi-layer bandaging system is the sum of the pressures exerted by each individual layer. Each of the four bandaging systems exerted different final pressures and gradients and different changes with posture change. These differences have important implications, which could influence the selection (or avoidance) of a particular bandage system according to a patient's condition and circumstances.*

Key Words: Multi-layer bandaging; Pressure measurement; Compression therapy; Chronic venous leg ulcer.

Introduction

The four layer bandaging system has been shown to produce satisfactory healing rates in chronic leg ulcers.[1,2] A number of alternative four layer bandage systems are commercially available and whilst they generally have similar properties it is unclear whether the overall pressures and pressure profiles obtained are the same. There have been several recent clinical trials involving multi-layered bandaging,[3–7] but few laboratory studies.[8–10]

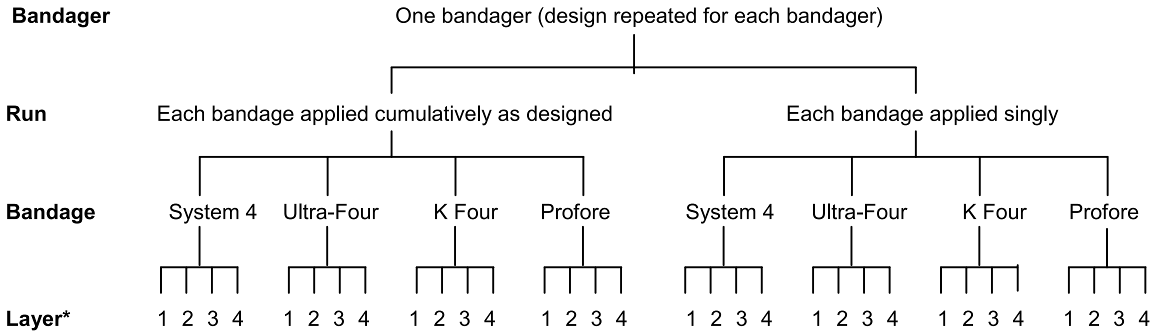
Many factors can influence the pressure obtained, for example, type and make of bandage, experience of the bandager, pressure measuring device and patient characteristics. Laboratory studies can be designed to reduce some of the sources of variability. In a series of experiments we initially compared three different pressure measuring devices.[11] Next we analysed data when four commercially available four-layer bandaging systems were applied on models.[12] We now compare the same bandaging systems when applied on the leg.

Materials and Methods

Bandages

The bandage systems chosen for the study were Profore Regular for ankle circumference 18–25 cm (Smith and Nephew), Ultra-Four (Robinson), System 4 (Seton) and K Four (Parema).

*Corresponding author. C. V. Ruckley, 1 Mayfield Terrace, Edinburgh, EH9 1RU, UK.



*pressure measured at three measuring points (ankle, gaiter and midcalf) at each of two aspects (medial and lateral) for each of the three postures (horizontal, sitting and standing) for each layer (first: wool; second: crepe; third: long stretch; fourth: cohesive).

The whole design was repeated for the three remaining bandagers. Thus the number of observations in the illustrated in figure (n=576) represents one quarter of the total (n=2304).

Fig. 1. Design of the study illustrated for one bandager only.

The four-layer system consists of a single layer of orthopaedic wool applied in a spiral from toe to knee, followed by a crepe bandage applied in a spiral, an elastic long stretch bandage applied by the figure of eight method and finally a cohesive bandage applied in a spiral. All bandages were applied in a standard fashion as recommended by the supplier. They were applied by four experienced bandagers (three nurses and one surgeon). A mirror was placed behind the leg to ensure accurate bandage placement and a 50% overlap throughout.

Measurements

There was one subject, a healthy, female volunteer. Her left leg was used in all experiments: ankle circumference 23.5 cm; mid-calf 40.0 cm. Pressure measurements were standardized throughout. Recordings were taken immediately after application, by means of the Borgnis Medical Stocking Tester (MST)[11]—at six points on the leg, namely the ankle (2.5 cm above the malleoli), the gaiter area (8 cm higher) and the mid-calf (11 cm higher) on both the medial and the lateral aspects for each of three different postures. This gave a total of 18 pressure measurements for each bandage application.

Postures

The three postures were: (i) standing with weight equally distributed on both legs; (ii) sitting with feet on the floor and knees at right angles; and (iii) horizontal with the subject lying on a bed with head and shoulders supported on pillows.

Application methods

To measure cumulative pressures, the bandages were applied and the 18 pressure readings were taken after each layer was completed. To measure individual pressures from the outer layers, fresh bandages were applied directly to the skin and the pressures recorded for each bandage separately. Each bandage was removed before the next one was applied. This enabled the cumulative bandage pressures to be compared with single layer bandage pressures.

The design of the study is illustrated diagrammatically in Fig. 1.

Statistics

Analysis of variance (ANOVA) was used to examine the effect of the various factors. It was not expected that the 18 observations relating to the three measuring points, two aspects and three postures would be independent. These factors, together with the bandage system by bandager interaction, were entered into the model as random effects to generate a covariance structure of the form we expected.

Table 1. Increase in cumulative pressure as a percentage of individual layer pressure.

Layer	Mean individual layer pressure (applied alone)	Anticipated pressure if effects additive	Mean cumulative pressure	Increase in cumulative pressure	Percentage (increase/individual pressure)
First: wool	6.1	6.1	6.1	–	–
Second: crepe	13.8	19.9	15.5	9.4	68.1
Third: long stretch	29.0	48.9	36.9	21.4	73.8
Fourth: cohesive	17.9	66.8	50.0	13.1	73.2

Results

A total of 2304 observations were made, generating 576 for each bandager, 576 for each bandage system, 1152 for cumulative layers only, 1152 for single layers only, 576 for each layer, 768 for each posture, 768 for each measuring point and 1152 for each aspect.

Differences in pressure between single and cumulative layers

One way to compare the pressures between cumulative and single layers is to calculate the difference in pressure obtained from applying the bandage cumulatively and the pressure obtained when the same bandage was applied alone, and perform a paired *t*-test. The first two layers have been described as providing protection rather than adding pressure, but we found that the pressure obtained after the third long stretch elastic layer was significantly ($p < 0.001$) higher than the pressure obtained by the third layer in isolation (mean difference 7.9 mmHg, 95% CI: 7.0–8.7). This indicates that the protective layers also contribute to the total pressure of the system.

Another way to examine the pressure between single and cumulative layers is to consider the increase in pressure generated by the most recent layer. This can be expressed as the percentage of the single layer pressure when used alone. When applied as part of a multi-layered system, each layer only adds—on average—approximately 70% of the pressure achieved by the same bandage applied alone (Table 1).

Using ANOVA as described in the methods, we find that there is no significant difference in the percentage of single layer pressure which is added to the cumulative layer among bandage systems ($p = 0.14$), bandagers ($p = 0.57$) or among the three final layers ($p = 0.38$). Thus, we have shown that a relatively consistent relationship exists between the single and cumulative layers with approximately 70% of the single layer pressure being added to the cumulative pressure.

Although the differences are not statistically significant ($p = 0.14$), we note that a lower percentage of single layer pressure is added to the cumulative pressure when the System 4 bandage system is compared to the other three bandage systems (Table 2).

The completed four layer systems

Table 3 shows the pressures under the four layer systems and the percentage change in pressure between the ankle and mid-calf. For clarity of

Table 2. Least square means for increase in cumulative pressure as a percentage of each individual layer pressure.

Factor	Level	Percentage of individual layer pressure added to cumulative layer		
		Least square mean	SE	*p*
Bandage system	K Four	74.1	3.81	0.14
	Profore	73.0	3.81	
	System 4	64.7	3.81	
	Ultra-Four	77.1	3.81	
Bandager	A	73.0	3.81	0.57
	B	76.3	3.81	
	C	70.5	3.81	
	D	69.2	3.81	
Layer*	Second: crepe	68.5	3.30	0.38
	Third: long stretch	74.4	3.30	
	Fourth: cohesive	73.8	3.30	

*Percentages differ slightly from the raw data quoted in Table 1 as measuring points, aspects, postures and the bandage system by bandager interaction are entered into the model as random effects.

presentation these are restricted to the standing and horizontal postures and the medial aspect of the leg which is the most common site for ulceration.

Using ANOVA as previously described, a significant difference in the final pressure was observed among bandage systems ($p = 0.005$) and among bandagers ($p < 0.001$).

The least square means for these main effects are given in Table 4. The final pressures differed among the measuring points and postures and between the medial and lateral aspects depending on the bandage system. The difference in pressure between the medial and lateral aspects ranged from 1.6 mmHg on the Profore to 6.3 mmHg on the Ultra-Four, with higher pressures on the lateral aspect for all four bandaging systems. The changes in pressures with changes in posture were similar for K Four and Ultra-Four and similar for Profore and System 4. The former two bandage systems had a larger change of mean pressure with the change from horizontal to standing (15 mmHg versus 10 mmHg). The mean pressures at each measuring point for each bandage system are given in Fig. 2. On average, there is a satisfactory gradient between the ankle and the gaiter for the K Four and Profore. However, it can be seen from Table 3 that this is not the case over all bandage systems, postures, bandagers and aspects.

Discussion

The four four-layer bandaging systems chosen for study are widely marketed in the UK and elsewhere. This experiment showed that these different systems produced differences in the pressures and gradients. This occurred despite careful experimental design in that fresh bandages were used for every application; the MST pressure monitor was chosen as the most

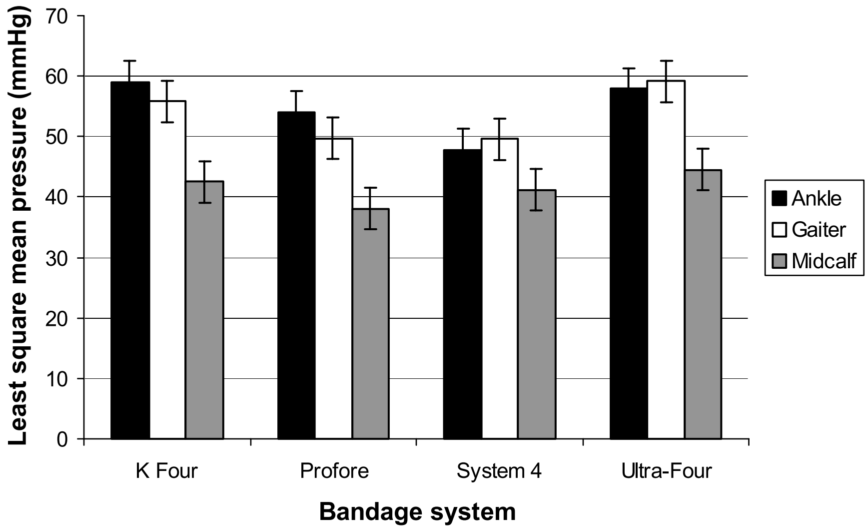


Fig. 2. Least square mean pressures obtained with the completed bandage systems over the three measuring points.

Table 3. Mean pressures (mmHg) for the completed system at the medial aspect.

Bandage system	Bandager	Horizontal				Standing			
		Ankle	Gaiter	Mid-calf	Percentage change in pressure from ankle to mid-calf	Ankle	Gaiter	Mid-calf	Percentage change in pressure from ankle to mid-calf
System 4	A	53	56	41	−22.6	56	68	40	−28.6
	B	49	48	43	−12.2	68	66	48	−29.4
	C	42	41	35	−16.7	58	58	43	−25.9
	D	37	38	35	−5.4	41	53	38	−7.3
Ultra-Four	A	46	53	44	−4.3	57	76	51	−10.5
	B	56	56	51	−8.9	75	76	59	−21.3
	C	53	51	35	−34.0	68	72	46	−32.4
	D	51	48	40	−27.5	70	67	49	−30.0
K Four	A	52	61	45	−13.5	57	76	53	−7.0
	B	51	52	48	−5.9	70	71	59	−15.7
	C	51	40	31	−39.2	71	59	39	−45.1
	D	45	44	38	−15.5	63	63	46	−27.0
Profore	A	48	47	43	−8.5	61	65	51	−16.4
	B	49	53	40	−18.4	67	67	42	−37.3
	C	41	38	31	−24.4	59	55	37	−37.3
	D	39	34	31	−20.5	51	50	36	−29.4

Table 4. Final pressure obtained using the four layer bandaging system.

Factor	Level	Final pressures obtained (mmHg)		
		Least square mean	SE	*P*
Bandage system	K Four	52.4	1.25	0.005
	Profore	47.3	1.25	
	System 4	46.2	1.25	
	Ultra-Four	53.8	1.25	
Bandager	A	54.0	1.25	<0.001
	B	54.1	1.25	
	C	46.9	1.25	
	D	44.8	1.25	

consistent on the basis of previous experiments;[11] maximum standardization was achieved by ensuring that each of four experienced bandagers applied standard bandaging techniques on the same leg, with a total of 2304 observations. These differences between bandaging systems are potentially important in that they may give rise to differences in both benefits and risks according to clinical circumstances. They also have training implications.

It is conventional teaching and clinical practice, albeit founded on a modest evidence base[8,9] that both bandaging and hosiery should deliver a continuous gradient of pressure maximal at the ankle and diminishing up the limb. In all cases in this study, in the hands of experienced bandagers, there were lower pressures at mid-calf than at the ankle. However, this did not always take the form of a continuous gradient, with gaiter pressures intermediate between the lower and upper pressures. The most favourable continuous gradients were produced with Profore, whereas the other three systems showed reversed gradient effects in that the mean pressure was higher at the gaiter than at mid-calf in around one in three cases. Such a profile could have deleterious effects on ulcer healing. Also, in our experience, this type of 'tourniquet' effect gives rise to patient discomfort and bandage intolerance. This leads to poor patient compliance with compression therapy, a common clinical problem.

Venous ulcers most commonly occur on the medial aspect of the lower leg. Whether pressure measurements should be taken on the medial or lateral side is a subject for debate. Overall, pressures were greater on the lateral aspect compared to the medial aspect with differences among the four bandaging systems. There was more evidence of a reversed gradient on the medial aspect than the lateral aspect. This was more pronounced whilst sitting or standing than when the leg was horizontal. These differences can be attributed to anatomical differences of curvature, tissue texture and muscle movement with posture. We consider that valid measurements can be made from either side of the leg, but the above observations should be borne in mind.

We have previously presented data on four layer systems applied to static models (cylinders and cones).[12] We observed that when an individual bandage was applied as part of a multi-layered system, it exerted 50–60% of the pressure exerted when applied alone. Table 1 shows the corresponding data for bandages applied to the human leg. We have tabulated the mean pressures achieved by individual layers when applied alone, the expected added pressure to a multi-layered system, if the pressures were additive, and the actual cumulative pressures observed. We found that when a bandage was applied as part of a multi-layered system, there was a damping effect, whereby it exerted approximately 70% of the pressure exerted when applied singly. Thus the commonly held assumption[13,14] that the effects of multiple layers are additive, is incorrect, both on models and on the leg.

It was considered important to examine the response of the bandaging systems to changes in posture. It is well known that compression systems of low elasticity (short or non-stretch) give rise to low pressures when the leg is horizontal or elevated but high pressures on standing. Compression systems with high elasticity (long stretch) deliver high pressures in both positions. There are therefore clinical advantages for both types of compression depending on the clinical circumstances. Systems with lower elasticity are generally agreed to confer larger safety margins for patients who have arterial or neurological impairment.

Given the damping effect of the multi-layer system on pressures and that the four systems are made up of combinations of different short and long stretch bandages, it is difficult to predict the effect of the system on change in posture.

In this study each system showed significant changes in mean pressure with changes in posture. On the elevated leg K Four and Ultra-Four produced pressures around 45 mmHg rising to around 60 mmHg on standing. Profore and System 4 produced pressures around 40 mmHg rising to around 50 mmHg. Pressures in the sitting position showed intermediate values in all systems. On the basis of the differences in postural changes in pressures observed, one could infer that K Four and Ultra-Four have higher overall elasticity than Profore and System 4.

We have shown that all four-layer bandage systems are not the same, and the professionals who provide care for venous disease should be aware of these differences.

References

1 Blair SD, Wright DDI, Backhouse CM. Sustained compression and healing of chronic venous ulcers. *BMJ* 1988; **297**: 1159–1161.
2 McCollum CN, Ellison DA, Groarke L, Fielden S, Connolly M, Franks PJ, *et al.* Randomised trial comparing Profore and the original four layer bandage. In: Leaper D, *et al.*, eds. *New Approaches to the Management of Chronic Wounds*. London: MacMillan, 1998: 30.
3 Callum MJ, Harper DR, Dale JJ, Brown D, Gibson B, Prescott RJ, Ruckley CV. Lothian and Forth valley leg ulcer healing trial. Part 1: Elastic versus non-elastic bandaging in the treatment of chronic leg ulceration. *Phlebology* 1992; **7**: 136–141.
4 Scriven JM, Taylor LE, Wood AJ, Bell PRF, Naylor AR, London NJM. A prospective randomized trial of four layer versus short stretch compression bandages for the treatment of venous ulcers. *Ann R Coll Surg Engl* 1998; **80**: 215–220.
5 Partsch H, Damstra RJ, Tazelaar DJ, Schuller-Petrovic S, Velders AJ, de Rooij MJ *et al.* Multicentre, randomized controlled trial of four-layer bandaging versus short-stretch bandaging in the treatment of venous ulcers. *Vasa* 2001; **30**: 108–113.
6 Whitman B, Barwell J, Davies C, Taylor M, Heather BP, Whyman MR, Poskitt KR, Earnshaw JJ. Cost effectiveness of surgery for venous ulceration: early results form the ESCHAR trial. *Br J Surg* 2003; **90**(Suppl. 1): 116. abstract.
7 Meyer FJ, McGuiness CL, Lagatolla NRF, Eastham D, Burnand KG. Randomised clinical trial of three-layer paste and four-layer bandages for venous ulcers. *Br J Surg* 2003; **90**: 934–940.
8 Sigel B, Edelstein AI, Savitch JHH, Felix R. Type of compression for reducing venous stasis. *Arch Surg* 1975; **110**: 171–175.
9 Lawrence D, Kakkar VV. Graduated static external compression of the lower limb: a physiological assessment. *Br J Surg* 1980; **67**: 119–121.
10 Hafner J, Botonakis I, Burg G. A comparison of multiplayer compression systems during rest, exercise and over 2 days of wear time. *Arch Dermatol* 2000; **136**(7): 857–863.
11 Ruckley CV, Dale JJ, Gibson B, Brown D, Lee AJ, Prescott RJ. Evaluation of compression therapy: comparison of three subbandage pressure measuring devices. *Phlebology* 2002; **17**: 54–58.
12 Ruckley CV, Dale JJ, Brown D, Gibson B, Lee AJ, Prescott RJ. Multi-layer compression: comparison of the individual and cumulative layers in four different four-layer bandage systems on models. *Phlebology* 2003; **18**: 123–129.
13 Thomas S. Bandages and bandaging: the science behind the art. *Care Practice* 1990; **8**(2): 56–60.
14 Thomas S. Bandages used in leg ulcer management. In: Cullum N, Roe BH, eds. *Leg Ulcers: Nursing Management*. London: Scutari, 1995: 63–74.