Original ARTICLE

COMPRESSION PROFILES OF ANTIEMBOLIC STOCKINGS

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ABSTRACT

Purpose: *To examine the compression levels and pressure profiles of 4 brands of thigh length antiembolic stockings (small, medium and large sizes) available in Australia and used for venous thromboprophylaxis.*

Method: *The computerised hosiery testing system of the independent Hohenstein Institute in Germany was used. This system allows separate and continuous pressure measurements in up to 20 test zones over the length of the stocking.*

Results: *Oapl (Anti-Embolism) stockings were unable to reproduce the recommended pressure gradient in any size, had low compression levels and commonly had reverse gradients. Kendall (TED) and Jobst (Anti-Em/GP) stockings had some inconsistent pressure gradients across sizes and reverse gradients particularly at maximum extension. Medi (Thrombexin climax) had consistent pressure gradients and achieved the recommended compression levels.*

Conclusion: *Some brands of antiembolic stockings would appear to be potentially ineffective for venous thromboprophylaxis. A quality standard for graduated compression stockings is recommended for development or adoption in Australia.*

INTRODUCTION

Venous thromboembolism (VTE) remains a major cause of morbidity and mortality in hospitalised patients[1]. Fortunately, the condition is able to be prevented in the majority as appropriate prophylaxis has been shown to reduce the incidence of VTE as well as the long term sequelae of this insidious condition[2]. In patients who are considered high risk for development of VTE, combined pharmacological and mechanical methods of prophylaxis are recommended[3] and are effective in reducing the risk of VTE[4].

Both pharmacological and mechanical methods of VTE prophylaxis have some associated complications. For instance, unfractionated heparins and to a lesser extent low molecular weight heparins are associated with an increased rate of postoperative bleeding[4]. Incorrect fitting of antiembolic stockings may cause skin ulceration[5] and their application in ischaemic limbs is not recommended[6]. Furthermore, when antiembolic stockings roll down the leg, they may cause a tourniquet effect thus obviating any prophylactic benefit.

Compliance with protocols for VTE prophylaxis has been found to be less than optimal in a number of published audits. George et al[7] found that 50% of patients in a general surgical unit did not receive appropriate prophylaxis. Even when a uniform policy for VTE prophylaxis was introduced, the compliance rate did not improve when retested one year later.

In addition to these problems with VTE prophylaxis, there have been concerns raised about the performance of some antiembolic stockings. Some studies[8,9,10] have reported a wide variation in both the levels of compression and the graduated compression profile between different brands of stockings. Indeed, these studies have even noted the presence of reverse pressure gradients in some brands! Clearly such reverse gradients would compound the problem associated with decreased venous return in immobilised patients and potentially lead to increased VTE rather than its prevention.

Despite the widespread use of antiembolic stockings for VTE prophylaxis, there is little information on the comparative performance of various stocking brands available in Australia. The aim of this study was to examine the levels of compression and the pressure profiles of 4 antiembolic stocking brands available in Australia and used for VTE prophylaxis.

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METHODS

The Hohenstein compression testing system[11] was used to examine the compression levels and the pressure profile of each antiembolic stocking. The Hohenstein compression testing system is a dynamic system able to undertake separate and continuous pressure measurements in up to 20 test zones over the entire length of the stocking. The stocking can be stretched to the minimal and maximal extent as designated by the stocking manufacturer. The computerised system is then able to measure compression levels and produce a pressure profile for any type, shape or size of stockings.

In thigh length antiembolic stockings, both Sigel et al[12] and Lawrence et al[13] described optimal compression levels of 18-20mmHg at the level of the malleoli decreasing to 8-10mmHg in the upper thigh. In addition, the stockings should exhibit a continuous pressure profile (pressure gradient) decreasing from the heel to the thigh (Fig.1). Thus the pressure measured in the upper thigh (position 14) should be approximately 40% of that measured at the level of the malleoli (position 2). A typical pressure profile is shown in Figure 1 beside a diagram of a leg with some of the measuring points and their ideal percentage pressures identified along its length. Both letters and numbers designate the measurement points used and recorded.

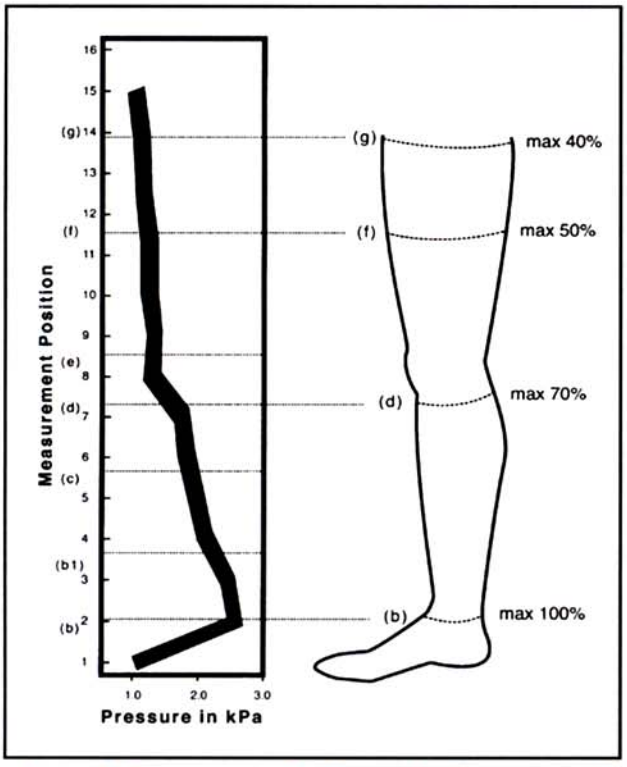

Figure 1. *A pressure profile illustrated with recommended compression levels and an appropriate pressure gradient. The measuring points shown on the graph correspond to the positions depicted on the leg.*

Thigh length antiembolic stockings available from four manufacturers were examined (Table 1). Each brand of stocking was assigned a number randomly for testing. A minimum of 4 stockings for each of 3 sizes was tested. The pressures recorded at each point along the length of the stockings are the average of three separate measurements for each individual stocking. Stockings were separately examined when stretched to their minimal extent and to their maximal extent as detailed by the manufacturer on the stocking packs (Table 2). Thus over 8000 separate pressure measurements were undertaken in this study.

RESULTS

The compression levels and pressure profiles for each size of stocking and for each stocking brand are graphically represented. In the graphs, the pressure profile at the minimal recommended circumference is represented by the solid line and at maximal recommended circumference by the broken line. The measurement positions correspond to those detailed in Figure 1.

Stocking 1 (Jobst: Anti-Em/GP)

Small Size (Figure 2a):

At the minimum circumference, there was virtually no pressure gradient. The highest compression was in the mid-calf (position 5) but this was only 0.92 KPa (6.9mmHg). At the maximum circumference, a gradient did exist between the lower calf (position 3) at 2.08KPa (15.6mmHg) and mid-thigh (position 12) at 0.8KPa (6mmHg). However, a reverse gradient existed between mid and upper thigh where the pressure rose to 1.27KPa (9.6mmHg).

Medium Size (Figure 2b):

At the minimum circumference, there was a poor gradient with maximum pressure of 1.2KPa (9mmHg) at position 3. At the maximum circumference, the pressure at position 2 was 1.92KPa (14.4mmHg) and a reverse gradient existed between the upper thigh (position 13) with pressure of 1.72 KPa (12.9mmHg) and the knee (position 8) with a pressure of 0.95KPa (7.1mmHg).

Large Size (Figure 2c):

The minimum circumference produced a gradient of 1.82KPa (13.6mmHg) at position 2 to 0.52KPa (3.9mmHg) at position 15. The maximum circumference had a pressure of 2.28KPa (17.1mmHg) at position 2 but a reverse gradient between position 13 at 1.66KPa (12.5mmHg) and position 8 at 1.01KPa (7.6mmHg).

Table 1

Stocking no.	Manufacturer	Item	Size	Number of Stockings tested
1	Jobst	111 625 Anti-Em/GP	small regular	4
		111 627 Anti-Em/GP	medium regular	4
		111 629 Anti-Em/GP	large regular	4
2	Kendall	3039 T.E.D.	small regular	4
		3144 T.E.D.	medium regular	4
		3221 T.E.D	large regular	4
3	medi	8062102 Thrombexin climax	small	6
		8062103 Thrombexin climax	medium	6
		8062104 Thrombexin climax	large	6
4	OAPL	41027A Anti-embolism St.	small regular	4
		41027C Anti-Embolism St.	medium regular	4
		41027E Anti-Embolism St.	large regular	4

Table 2

Stocking No.	Size	Circumference (cm) ankle	calf	thigh	Length (cm)
1	small	-	23-31	41-74	73-84
	medium	-	31-38	41-74	73-84
	large	-	38-46	41-74	73-84
2	small	-	<30.5	<63.5	<72.4
	medium	-	30.5-38.1	<63.5	<72.4
	large	-	38.1-44.5	<63.5	<73.7
3	small	20-22	-	48-60	-
	medium	23-25	-	56-70	-
	large	26-28	-	64-80	-
4	small	up to 18	up to 30	-	up to 82
	medium	18-24	30-38	-	up to 82
	large	24-30	38-46	-	up to 82

Stocking 2 (Kendall: TED)

Small Size (Figure 3a):

Neither minimal nor maximal circumferences produced a pressure gradient between ankle and thigh greater than 0.13KPa (1mmHg). In addition, the highest pressures occurred in the lower calf (position 4) and measured only 0.86KPa (6.5mmHg) at minimal circumference and 1.44KPa (10.8mmHg) at maximal circumference. Reverse gradients were also present between thigh and knee.

Medium Size (Figure 3b):

A pattern similar to the small size stockings existed in the medium size. The maximum pressure at position 2 was 1.19KPa (8.9mmHg) at minimal circumference and 1.82KPa (13.7mmHg) at maximal circumference. A reverse gradient also existed between upper thigh and knee.

Large Size (Figure 3c):

A pressure gradient did exist in the large size. However, at minimal circumference the pressure at position 2 was only 1.69KPa (12.7mmHg) and in the upper thigh (position 13) the pressure was 0.65KPa (4.9mmHg). At maximal circumference, the respective pressure values for positions 2 and 13 were 2.01KPa (15.1mmHg) and 1.0KPa (7.5mmHg). A small reverse gradient was also present between thigh and knee.

Stocking 3 (Medi: Thrombexin climax)

In all 3 sizes of stockings, an appropriate pressure gradient existed and there were no reverse gradients (Figures 4a,b & c). The pressures at the ankle at minimal and maximal circumferences were within 0.26KPa (2mmHg) of each other for all sizes. In the small size, the ankle and thigh pressures were respectively 2.09KPa (15.7mmHg) and 0.82KPa (6.2mmHg) at minimal circumference, and 2.36KPa (17.7mmHg) to 1.22KPa (9.2mmHg) at maximal circumference. In medium size, the pressures were 2.35KPa (17.6mmHg) to 0.75KPa (5.5mmHg) and 2.51KPa (18.8mmHg) to 0.99KPa (7.4mmHg). The large stocking size pressures were 2.5KPa (18.8mmHg) to 0.71KPa (5.3mmHg) and 2.62KPa (19.6mmHg) to 1.07KPa (8mmHg).

Stocking 4 (Oapl: Anti-Embolism)

Small Size (Figure 5a):

Virtually no pressure gradient existed at minimal circumference and the highest pressure at position 2 was only 0.48KPa (3.6mmHg). At maximal circumference, there was a reverse gradient from upper thigh (position 13) with a pressure of 1.41KPa (10.6mmHg) to ankle (position 2) where the pressure was 0.66KPa (4.9mmHg).

Medium Size (Figure 5b):

At minimal circumference, virtually no pressure gradient existed with pressures recorded between 0.79KPa (5.9mmHg) at position 3 and 0.86KPa (6.5mmHg) at position 13. At maximal circumference, pressure at the ankle (position 2) was 1.82KPa (13.7mmHg) and at the knee (position 8) was 1.17KPa (8.8mmHg) but then a reverse gradient occurred with pressure rising in the upper thigh (position13) to 1.73KPa (13.0mmHg).

Large Size (Figure 5c):

At minimal circumference, little pressure gradient existed with the ankle pressure (position 2) of 1.39KPa (10.4mmHg) and the mid-thigh pressure (position 11) of 1.31KPa (9.8mmHg). At maximal circumference, a minor gradient existed with pressures 1.98KPa (14.9mmHg) at position 2 and 1.41KPa (10.9mmHg) at the knee (position 7) but then a reverse gradient occurred with mid-thigh pressure of 2.44KPa (18.3mmHg).

DISCUSSION

The effect of graduated compression on lower limb circulation has been the focus of considerable research. Non-graduated leg compression was considered by Sigel et al[12] to be suboptimal for improving venous return in comparison with graduated compression. They used a five chamber pneumatic sleeve from ankle to thigh in a foot down position and showed consistently increased venous blood velocity using a pressure gradient of 18mmHg at the ankle and 8mmHg at the thigh. Thus the 18/8 pressure profile gained some prominence.

Lawrence and Kakkar[13] used a similar pneumatic compression device with five chambers and confirmed Sigel's findings. They concluded that in the recumbent position, externally applied graduated compression of approximately 20mmHg at the ankle reducing to 10mmHg in the upper thigh produces substantial increase in deep venous blood flow velocity as well as muscle blood flow and subcutaneous tissue flow. In addition, Lawrence and Kakkar found that when the pressure was applied only below the knee, the increase in venous blood velocity was not significantly different from that produced when the whole limb was compressed.

A large number of clinical studies have shown the benefit of antiembolic stockings with a pressure profile approximate to that suggested by Sigel, Lawrence and Kakkar. In a meta-analysis of 7 studies, Colditz et al[14] demonstrated that surgical patients suffering from a malignancy and wearing antiembolic stockings had VTE risk reduction from 27% to 11% and a further reduction to 6% when combined with unfractionated heparin. Wells et al[15] also conducted a review of 11 randomised trials in which graduated compression stockings had been employed. They

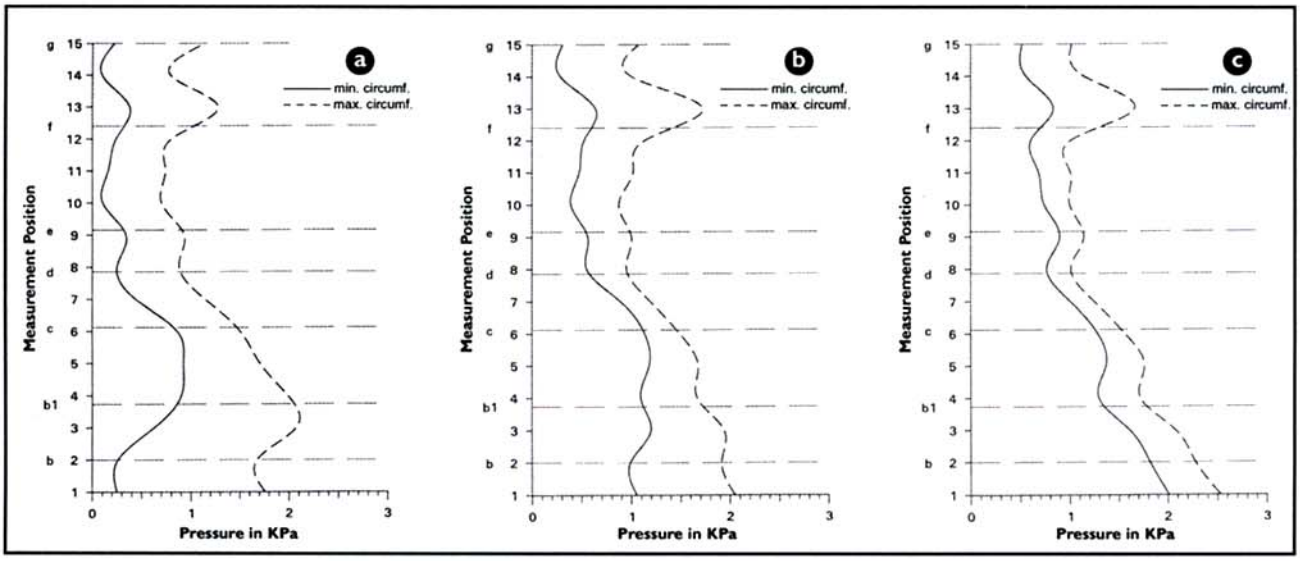

Figure 2 (a, b & c). *The pressure profile and compression levels of Jobst (Anti-Em/GP) stockings in small (a), medium (b) and large (c) sizes.*

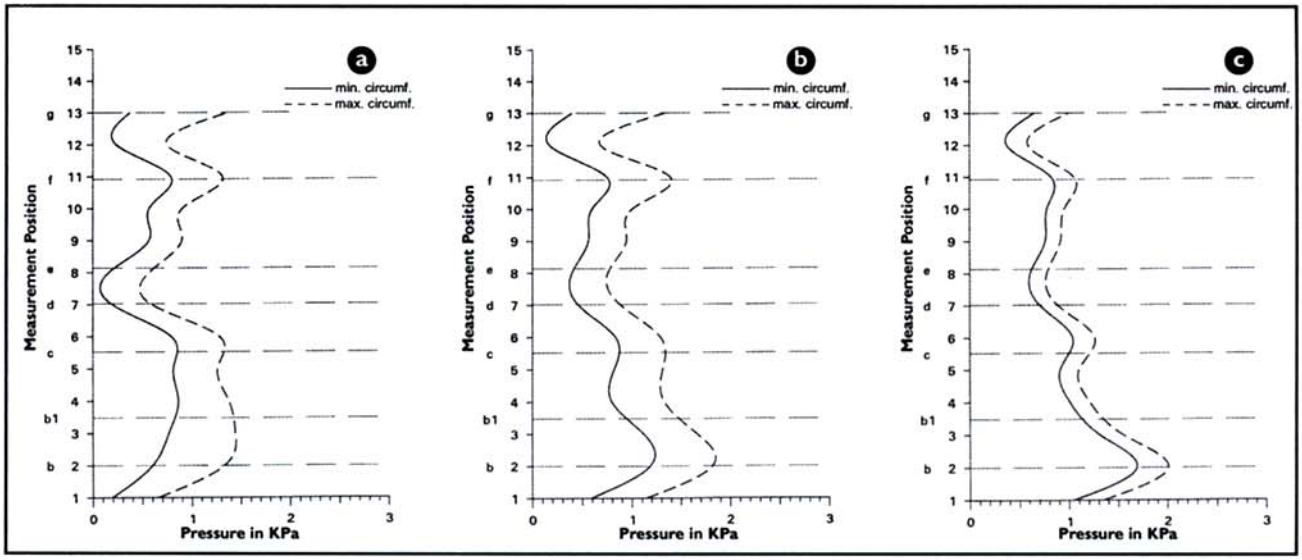

Figure 3 (a, b & c). *The pressure profile and compression levels of Kendall (TED) stockings in small (a), medium (b) and large (c) sizes.*

concluded that wearing graduated compression stockings was associated with a 68% risk reduction for VTE.

It is evident that wearing graduated compression stockings for VTE prophylaxis in appropriate patients reduces but does not eliminate the risk of VTE. The compression stockings have to be correctly fitted to the individual and properly worn in a continuous manner during the period of immobility. For instance, the stockings should be prevented from rolling down the limb where they may act as a tourniquet or cause skin ulceration[5]. However, it is reasonable to conclude that for the individual patient wearing antiembolic stockings in the recommended manner, there is an expected risk reduction for VTE.

Thigh length graduated compression stockings prescribed for VTE prophylaxis should ideally have compression levels of 18-20mmHg at the ankle and provide a pressure profile of 100% at the ankle, 70% at the knee and 40% in the thigh[12,13]. Importantly, each size of antiembolic stocking should be able to reproduce this profile whether they are extended minimally or maximally and indeed this should be consistent in all brands. In addition, there should be an adequate range of sizes to fit the legs of the majority of the patient population.

Standardisation of antiembolic stocking manufacture and testing would be a major benefit to ensure a quality product. In Germany, all compression hosiery undergoes compulsory testing at the designated independent testing centre, the Hohenstein Institute, using the computerised equipment described above. Medical compression hosiery meeting the specified quality requirements may be labelled with a specific German seal of quality. In the UK, British

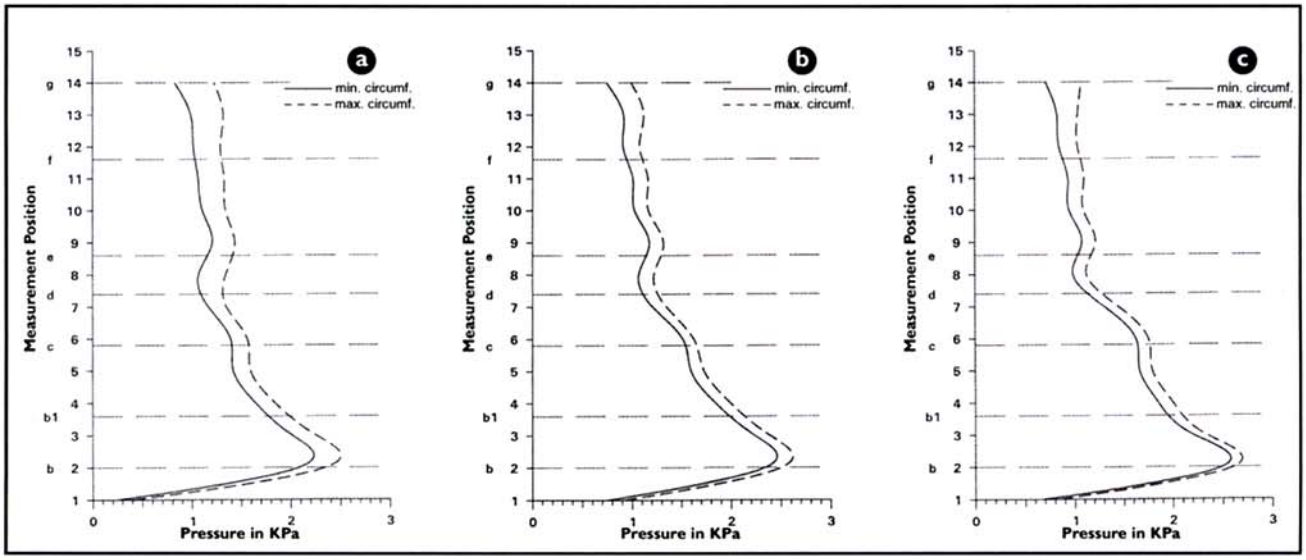

Figure 4 (a, b & c). *The pressure profile and compression levels of Medi (Thrombexin climax) stockings in small (a), medium (b) and large (c) sizes.*

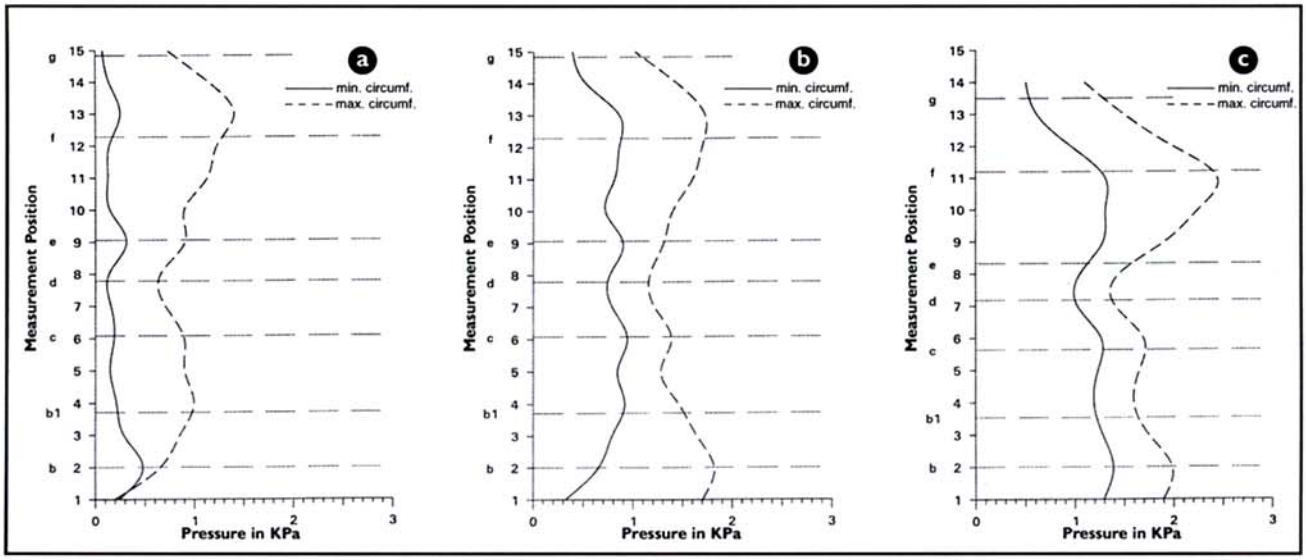

Figure 5 (a, b & c). *The pressure profile and compression levels of Oapl (Anti-Embolism) stockings in small (a), medium (b) and large (c) sizes.*

Standard 6612 has been developed for graduated compression hosiery and testing is performed on a Hatra hosiery pressure tester. Hosiery complying with the specifications for BS 6612 may be so labelled. Currently, there are attempts to produce a uniform European standard for compression hosiery incorporating one or both of these testing methods.

Clinicians should be concerned if antiembolic stockings are not able to reproduce an appropriate pressure gradient with appropriate levels of compression at the ankle and thigh. Such concerns certainly have been raised previously[8,9,10]. In a detailed study, Thomas et al[16] tested six brands of antiembolic stockings available in the UK using the Hatra hosiery pressure tester. They found that two brands "left much to be desired in terms of their graduated compression profiles and stiffness values". Both of these brands are available in Australia and were also part of the current study.

The current study found that the Oapl (Anti-Embolism) stocking was not able to produce the recommended pressure gradient in any size, there were widely divergent pressure profiles with the stockings at their minimum or maximum circumference and the highest compression levels were generally below 1.85KPa (14mmHg). Reverse gradients from knee to thigh were common particularly at maximal extension. It is difficult to believe that these stockings can be effective in VTE prophylaxis given these results. Interestingly, although Oapl claims to have subjected their stockings to testing "using guidelines in BS 6612" (company literature), this does not appear to have included testing on the Hatra equipment as required for compliance with that British standard.

The Kendall (TED) and Jobst (Anti-Em/GP) stockings had similar problems to each other. There was some inconsistency in their pressure profiles and inadequate compression levels across the sizes. In both brands, the largest size stockings tested produced the best results. Unfortunately, both brands commonly exhibited reverse gradients in all sizes particularly at maximal extension. Interestingly, these results are similar to the findings reported by Thomas et al[16] when they tested these same 2 brands using a different testing system (Hatra).

The only antiembolic stocking giving consistent results in pressure profile and levels of compression in all sizes tested was Medi (Thrombexin climax). Again, this was one of the stockings tested by Thomas et al[16] and the results are similar despite different testing equipment and methods.

The information printed on individual stocking packs of some brands was found to be confusing and there is no consistency across brands in the information provided. Furthermore, literature available from some manufacturers promoting their various brands was not infrequently at odds with the details printed on the stocking packs. Much better clarity and consistency of information is required in order to ensure that patients are not inadvertently fitted with an incorrect size. Optimal VTE prophylaxis requires correctly sized and fitted stockings for each individual patient.

The results of the pressure profiles and compression levels of the tested antiembolic stockings in this study would suggest that some brands are potentially ineffective for VTE prophylaxis. In choosing an antiembolic stocking for patient prophylaxis, the result of this study, the study by Thomas et al[16] and the concerns raised about various stocking brands in other articles[8, 9,10] ought to be considered. Furthermore, it is essential for the protection of patients requiring VTE prophylaxis that a quality standard for antiembolic stockings is developed or adopted in Australia.

ACKNOWLEDGMENTS

This study was made possible by a research grant provided by SSL (Australia).

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