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## Anti-embolism Stockings, the similarities and differences

**Abstract:** The medical textiles sector is growing annually, estimated to reach \$2.7 billion by 2018 [1]. Predominantly attributed to the growing and ageing population, and consequently there has been a vast increase in venous disorders. Currently 61% of the British population are thought to be at risk of deep vein thrombosis (DVT) [2] of which the majority is avoidable given the correct prophylaxis [3]. Anti-embolism stockings (AES) are used to prevent DVT when hospitalised patients are supine for long periods of time. The market place is competitive, with numerous brands striving to win the local British National Health Service (NHS) contract. It is a commodity market, with low profit margins but high volumes. The aim of this research was to seek an understanding of the AES on the market, exploring the different construction techniques, knit notations and yarn characteristics in 3 popular AES brands, with the overall aim of providing a basis of knowledge to improve product development, product efficacy and ultimately save lives.

**Keywords:** MEDICAL TEXTILES, COMPRESSION, ELASTANE, GRADUATED.

Anti-embolism stockings (AES) are a specific modality in the prevention of deep vein thrombosis (DVT) for non-ambulatory patients. AES differ from all other compression stockings as they exert a specific pressure profile which was discovered in 1975 by Bernard Sigel [4]. This graduated profile maximises venous return, commonly referred to as the Sigel profile or “The Gold Standard” [5]. The profile is detailed as 18mmHg at the ankle, 14mmHg at the calf, 8mmHg at the popliteal, lower thigh 10mmHg and upper thigh 8mmHg [6-16]. An accumulation of factors when a patient is supine leads to the higher risk of thrombi formation, but it is mainly due to the lack of movement of the foot and calf muscle which is known to pump blood back to the heart with each contraction [16], without this movement blood is more likely to pool and coagulate contributing to DVT. This risk is further complicated with surgery [8,10,16,17-20], where it is suggested that up to 40% of surgical patients will develop DVT (21).

DVT is often referred to as a silent killer, as it can lead to sudden death due to pulmonary embolisms (when a thrombi blocks an artery to lung or heart), estimated to claim 27,000 lives in the UK every year [3]. DVT is one of the most common preventable diseases [2,6,12], however, research states that in 2005 around 70% of UK hospitalised patients did not receive any prophylaxis at all for DVT prevention [22].

AES is the preferred modality for prevention of DVT [6,27] due to ease of use and no added risk of patient bleeding. When correctly administered, AES is a powerful prophylaxis which can minimise the risk of DVT by up to 68% [11,28-30]. Combine AES with the use of pharmacological intervention and this rises up to 85% [5-7,25,31].

Globally there is no consensus on the test procedure or the equipment for analysing the effectiveness of AES. Currently there are 4 main test methods; British Standard BS7672 [32], German RAL-GZ 387:2000 [33], European CEN/TR 15831:2009 [34] and French AFNOR G 30.102 [35]. For knee length AES the following guidelines are in place; the British Standard stipulates 2 test points at 10cm and 31cm above the footplate, using Hatra test equipment. RAL stipulates 4 test points between 10-44cm dependent upon leg size, using Hohenstein machinery. CEN stipulates 4 test points at heights corresponding to the manufacturer’s guidelines, on a tensile testing machine. AFNOR has only 1 measurement point for knee length AES, at the ankle circumference and uses a tensile tensometer to test. 4 fixed measurement points at 12,

20, 31 and 39cm from the heel were chosen for this comparative work, this was to gain as much insight into the pressure profiles of the products as possible. All of standards utilise indirect methods of measurement and capture a force which is converted using the Laplace law to a pressure in mmHg. Where,

$$P=T/r$$

Where P = Pressure (Pa), T = tension in cylinder wall (N/m), r = radius of cylinder (mm).

The Laplace law was initially introduced in the 19<sup>th</sup> Century, the aim was to mathematically describe the relationship between wall tension of water droplets, to radius and cavity pressure [36]. Laplace law has since been adapted and utilised in the medical compression sector for many years [32-35,37-39]. The effectiveness of the Laplace Law in compression has been questioned [40] as it fails to take into account several factors including the variable nature of textile fabrics, yarns and the human anatomy, however its efficacy has been proved (41) and it is still used today.

All AES should exert the graduated Sigel profile as mentioned above, which exerts the largest pressure at the ankle then gradually decreasing to the knee. A graduated profile is imperative from the ankle to aid in the interstatic pressure and prevent blood pooling in the lower extremities. All AES use elastane or elastodiene [33] as the driving factor in compression and nylon as the knitted yarn. AES are knitted on circular knitting machines with the elastane (covered or uncovered) either knitted, laid or tucked into the structure. The stitch length is controlled by varying the input tension of the elastane and nylon and/or adjusting stitch cams.

There is an array of conflicting evidence of the effectiveness of AES [3,12,29,42], but in part the confusion is due to the wide range of manufacturers producing product to and testing against different standards, using different test equipment, having different sizing strategies and it could also be attributed to poor fitting and incorrect use of the product.

There is little current information published on the technical construction of AES [43,44], which limits development of new and improved product structures and yarns.

### ***Methodology***

Three brands of stockings currently on the market were sourced and utilised for this research, referred to as AES1, AES2 and AES3.

#### *Fabric Structure Analysis*

Each structure was unravelled course by course under high magnification, recording the knit notation until certain of the structure's pattern repeat. This was further verified with Scanning Electron Microscope (SEM) analysis.

#### *Yarn details*

The SEM was used to analyse the details of the yarns. Each yarn was carefully removed from the structure, mounted onto a stub and placed in SEM at a working distance of 15mm, under magnification of 40-350x. Yarn types were qualitatively analysed and described, the number of filaments were counted and diameter measured.

#### *Fibre content*

The fibre content of the full stockings was measured. The stockings were weighed according to ISO-1833-1 (2006) and then the elastane was dissolved from full stockings using dimethylacetamide (DMA) following procedure BS EN ISO 1833-20:2010. The remainder was rinsed, then oven dried and reweighed, therefore determining the amount of nylon present. 2 full stockings were used from each brand AES1, 2 and 3.

The stockings were then re-tested to see if the fibre composition changed throughout the stocking. The method described above was repeated but the elastane was dissolved from 5cm depth portions of the stocking corresponding to heights of 12, 20, 31, 39cm, referred to as A, B, C and D.

### *Stitch Length*

The Shirley Crimp tester was utilised to measure the length of yarns removed from AES and enable the calculation of stitch length. Issues were encountered due to the crimp tester having been originally designed for woollen and worsted yarns. No standard testing procedure was available for bulked nylon, therefore the following method was developed.

10 elastane yarns and 10 nylon yarns were carefully removed from each course. The yarns were placed on the Shirley Tester and the yarn tensioning weight was calculated as tex x 0.6. The yarns also too long to fit into the Shirley Tester so, each yarn was cut in half and each half was measured, the lengths of the 2 halves were added together and then divided by the number of needles used on the machine.

### *Yarn Tex*

10 samples of yarn were carefully removed from each structure and a 10cm length was cut from each. Each sample was weighed and the yarn count in Tex was estimated. It is clear that due to the external knitting forces and tensions applied during the knitting this is not an accurate method to obtain the original tex, however it provided an indication for comparative purposes.

### *Pressure Capability*

5 samples of each of the 3 brands of AES were sourced and 50mm depth specimens were cut out at heights of A-12, B-20, C-31, D-39cm (measured from the heel). The 60 specimens were cycled 6 times at a test rate of 60mm/min on an Instron 3345, with a load cell of 5000N and circumferential gauge length was 100mm. On the sixth extension the force required to extend the samples to a circumference shown in Table 1 was recorded. This circumference was based on the manufacturer's smallest size guidelines on the packaging. Often only one measurement was given, in this case the RAL [33] data points were used to complete the leg profile. The Newtons force (N) values obtained from the Instron were converted to a pressure of mmHg using an adaptation of the Laplace Law, taking the circumference into consideration;

$$\begin{aligned} \text{Pressure (mmHg)} &= \left( \frac{628.319T}{133.322} \right) c^{-1} \\ &= (4.713T) c^{-1} \end{aligned} \quad [41]$$

Where T = tension, c = circumference of cylinder (cm).

Sample	Circumference at Measurement (cm)			
	A	B	C	D
AES1	18	24	31	30
AES2	19	25	32	31
AES3	23	29	36	35

Table 1 circumference the samples were extended to on the Instron based on manufacturer guidelines.

## Results

### Fabric Structure

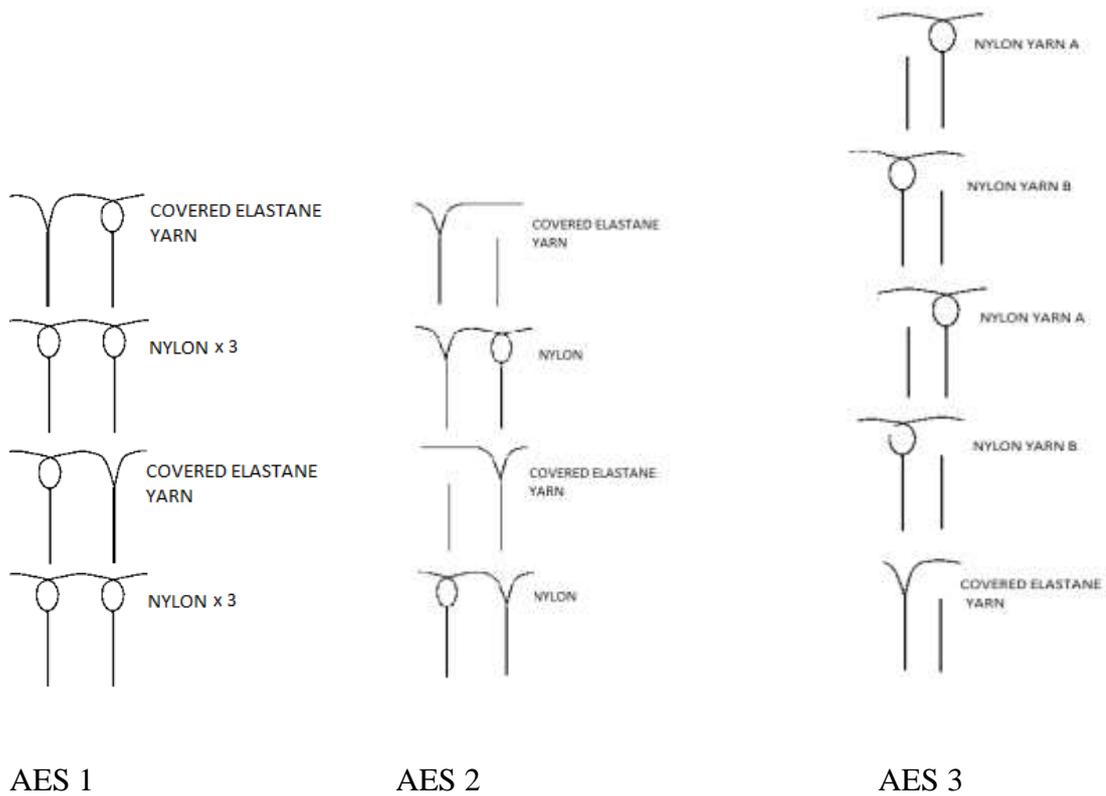


Figure 1 – Knit Notation of the 3 Brands of AES

It is clear from the knit notations that each of the Brands of AES use different structures in their endeavour to achieve the Sigel Profile. AES1 opting for a simple knit and tuck combination with two yarn types. AES2 utilise knit, tuck and miss with two yarn types. AES 3 use knit, tuck and miss with 3 different yarns.

### Yarn Details

Sample	Elastane filament count	Diameter elastane filament ( $\mu\text{m}$ )	Elastane total diameter ( $\mu\text{m}$ )	Covering Yarn filament count	Diameter Covering yarn ( $\mu\text{m}$ )	Method of covering	Nylon Filament Count	Diameter Nylon yarn ( $\mu\text{m}$ )
AES1	36	31	228	34	32	single covering	34	18
AES2	10	42	182	10	20	double covering - 5 yarns each	70	11
AES3	10	48	180	13	22	single covering	23	elastane monofilament wrapped in nylon Yarn A = 21 <i>Elastane yarn = 52</i>
							13	Yarn B = 22

Table 2 SEM details on yarn diameter and counts across AES1, AES2 and AES3

Table 2 and figures 2-8 show the distinct differences in the choices made by the manufacturers of AES. The manufacturer of AES1 chose a significantly higher filament count of elastane than the manufacturers of AES2 and AES3. Perhaps this is linked to why elastane is only needed every fourth course as opposed to every second on AES2.

AES2 and 3 chose elastanes with very similar appearance and metrics, however, AES3 used a single covering of the elastane and AES2 a double covering.

AES2 had a significantly higher knitting yarn count than AES1 and 3, with 70 individual filaments each 11 $\mu\text{m}$  in diameter.

Figure 9 shows AES3's unique feature of an elastane monofilament of 52 $\mu\text{m}$  diameter, added to the nylon knitting yarn A. This yarn is comprised of 23 filaments of bulked nylon wrapped around an elastane core. This allows the structure to knit the main elastane every 5<sup>th</sup> course, as opposed to every second or third as AES1 and AES2, whilst retaining the pressure required, representing a cost saving as overall achieving a lower usage of elastane.

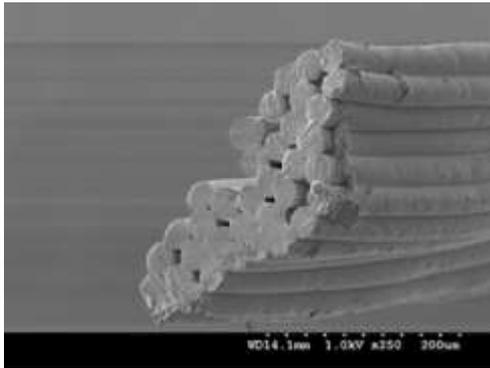


Figure 2 - AES1 Elastane

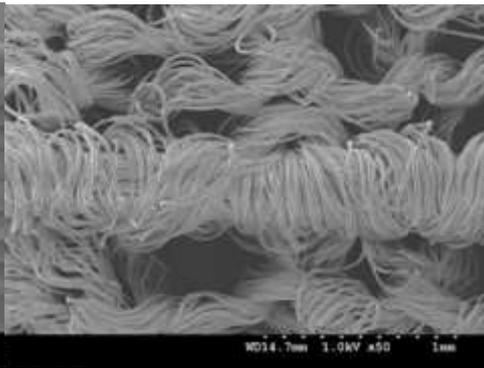


Figure 3 - AES1 knit construction

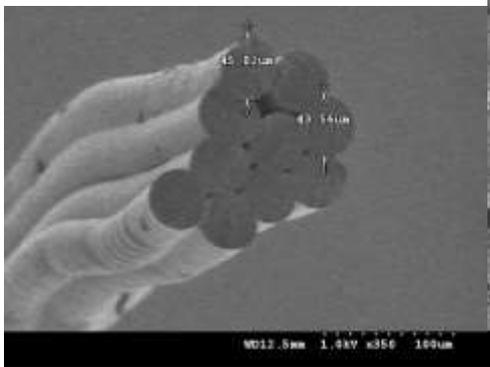


Figure 4 - AES2 Elastane

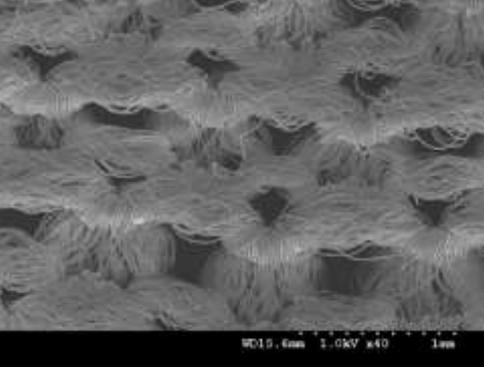


Figure 5 - AES2 Knit construction

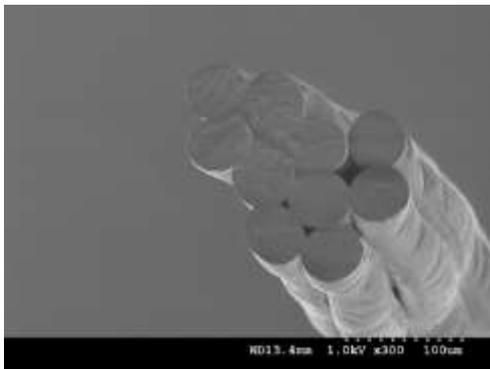


Figure 6 - AES3 Main elastane

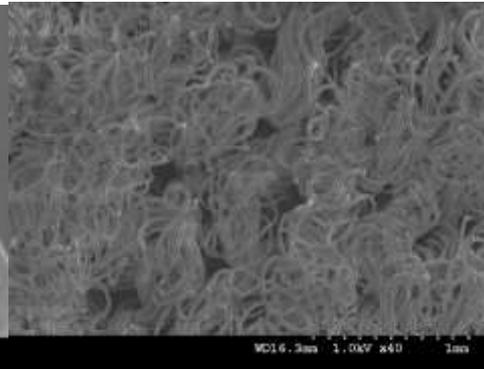


Figure 7 - AES3 Knit Construction

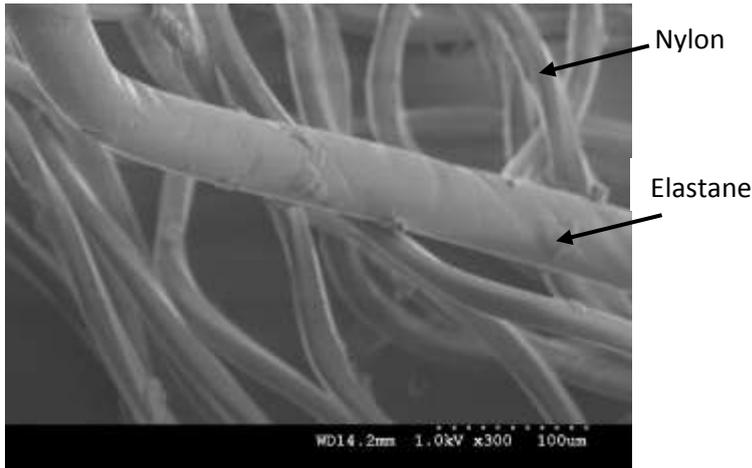


Figure 8 – AES3 additional elastane amongst nylon yarn A

**Fibre Content**

BRAND	Chemical analysis results %		Manufacturers packaging %		% difference from manufacturers packaging	
	Nylon	Elastane	Nylon	Elastane	Nylon	Elastane
AES1	87.05	12.95	79	21	+10	-38
AES2	81.14	18.86	83	17	-2	+11
AES3	85.31	14.69	85	15	0	-2

Table 3 – Mean % elastane and nylon from chemical dissolution and the difference between chemical analysis and manufacturers packaging.

Table 3 showed that manufacturers used similar proportions of the same filament types to make their AES, containing approximately 81-87% nylon and 13-19% elastane. The fibre content of AES2 and AES3 were verified through chemical analysis, however AES1 was found to contain significantly less elastane (and more nylon) than the stated % fibre content on the packaging, contravening EU textile labelling Regulations [45].

Further chemical analysis of 4 portions of each AES, taken from height positions A12, B-20, C-30, D-39cm.

AES BRAND	Nylon % (%change from A)				Elastane % (%change from A)			
	A	B	C	D	A	B	C	D
AES1	87.7	86.4(-1.5)	85.4(-2.6)	85.1(-3.0)	12.3	13.6(+11)	14.58(+19)	14.9(+21)
AES2	81.8	79.0(-3.4)	77.4(-5.4)	78.0(-4.7)	18.2	21.0(+15)	22.6(+24)	22.3(+23)
AES3	83.1	83.1(0)	83.4(+0.4)	82.7(-0.5)	16.9	16.9(0)	16.6(-1.8)	17.3(+2.4)

Table 4 - Average nylon and elastane content of 2 samples taken from position A, proceeded by the increase or decrease in fibre content shown as a percentage of A.

Table 4 showed that AES1 contained a significantly larger percentage of nylon at the ankle than the other 2 brands. AES2 contained the lowest nylon and largest portion of elastane.

AES1 progressively decreased the nylon content as the stocking was knitted from A-D and the elastane progressively increased.

AES 2 had a similar trend in that A had the lowest proportion of elastane, however, the percentage increased until C and then decreased slightly. The inverse happened with the nylon.

AES 3 presented a different trend, there was no difference between portion A and B of the stockings and very little difference between A-D. No particular trend was noted.

It is clear that AES1 and AES2 had very similar development ideas, in terms of fibre proportion, about how to attain the Sigel Profile. AES3 didn't follow a particular trend, with very little change from A-D.

**Stitch Length**

AES BRAND	ELASTANE (cm)				NYLON (cm)			
	A	B	C	D	A	B	C	D
AES1	0.03	0.04	0.05	0.05	0.25	0.26	0.29	0.29
AES2	0.03	0.03	0.04	0.04	0.31	0.32	0.33	0.34
AES3	0.04	0.05	0.05	0.06	0.14*	0.16*	0.17*	0.18*

Table 3 – Average stitch length in cm, where \* denotes nylon yarn B

It is clear from Table 3 that there was significantly more nylon in each course than elastane in all AES. Suggesting that the elastane was fed into the knitting machines at higher tension than the nylon. Table 3 also shows that very small adjustments are all that is required to achieve a graduated tension profile and highlights just how precise the process of AES manufacturing can be.

AES1 increased the stitch length of both elastane and nylon incrementally from A to C/D to accommodate the dimension of the limb and suggesting a minimum of 2 changes of input tension for both yarns.

AES2 indicated only 1 change in tension of the elastane across the length of the stocking. AES2 also had a significantly larger stitch length of nylon across the 3 stockings in the 4 sections.

AES3 showed an elastane stitch length change a minimum of 2 times, however, opted to have B and C the same, whereas AES1 chose C and D the same stich length. The nylon however, showed a completely unique story with 2 yarns at significantly lower stitch lengths than AES1 and AES2. Since AES1 and AES2 had elastane more frequently, perhaps AES3 opted to utilise the nylon and the nylon/elastane yarns to aid in the compression profile.

It is noted that although the data suggested the minimum number of input tension changes, it is possible to have smaller incremental changes in between those noted here as yarn feeding mechanisms can input tension at 0.1g increments.

**Yarn Count in Tex**

Brand	Tex of elastane	
	Nylon	Elastane
AES1	8.4	68

AES2	33.1	39
AES3	5.5* 8.8	38

Table 5 – Estimated yarn count of nylon and elastane used in AES, \* denotes nylon yarn B.

Table 5 showed that each manufacturer used a different combination of counts of yarns in their endeavour to achieve the Sigel Profile.

AES1 was made from elastane with a significantly higher count than AES2 and 3. This is perhaps partly due to the 36 filament elastane yarn utilised and also perhaps aligns with only adding elastane every 4<sup>th</sup> course. This AES1 also had the lowest percentage elastane compared to AES2 and 3. Suggesting that higher numbers of filaments and higher tex requires less frequency of elastane.

AES2 and AES3 used very similar elastane counts, perhaps the same yarn, corroborated by the SEM evaluation in Table 2. There were small variations in the results, representing both possible production variability and measurement inaccuracy.

All manufacturers take a different direction where the nylon is concerned. AES1 using a low tex yarn, AES2 a significantly higher tex, AES3 using 2 nylon yarns, each of differing tex and one also containing elastane.

### *Pressure capabilities*

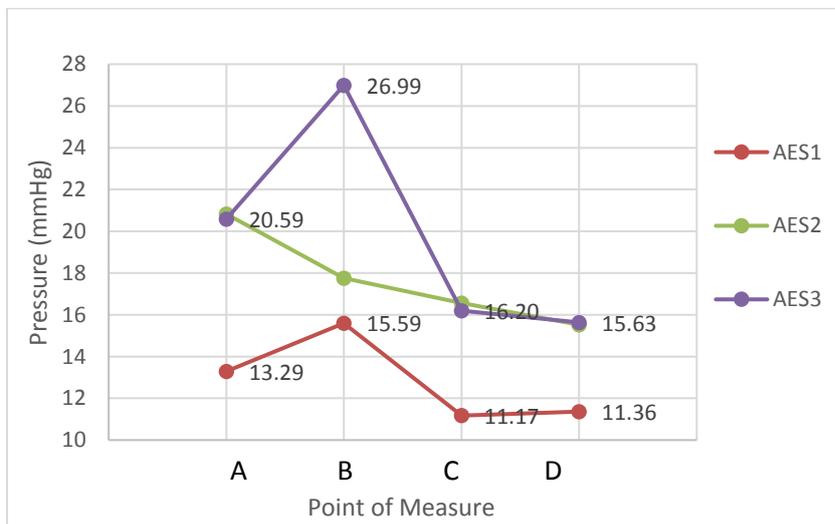


Figure 9 Pressure profiles of AES1, AES2, AES3 calculated from Instron tension measurements.

Figure 9 showed that only one Brand, AES2, achieved a graduated profile. AES1 and AES3 showed a very different profile, peaking at point B, instead of A, which could cause a reverse gradient and would certainly impair the efficacy of the product.

Interestingly, had BS 7672[32] been followed, which requires data at only point A and D, rather than the 4 measurement points taken here all products would have shown a graduated profile

and have been approved (as long as AES2 and AES3 stated 18mmHg on their packaging). This is extremely concerning as the ankle pressure exerted by the stocking is considered by many to be the most important anatomically to ensure correct pressure in the veins and aid in the blood flow.

Another point to note is the range of ankle pressures measured ranged from 13-21mmHg at the lowest circumference according to the manufacturers packaging. The required ankle pressure is 10-18mmHg according to the British Standard BS7672 with an allowance of 20% from any manufacturer's stated ankle pressure. Giving a maximum of 21.6mmHg if the manufacturer states the ankle pressure of 18mmHg. This suggests that although AES2 showed a graduated profile, within tolerance at the smallest circumference it might not be the same at the largest circumference.

## Conclusion

It is clear that different brands take a very different approach to manufacturing AES, perhaps as they use different testing technology to assess the effectiveness of their products. The AES explored were manufactured with a combination of different yarns in terms of the number of filaments in the yarns, yarn count and covering methods. However, all brands use the same basic fibre types of elastane and bulked nylon.

This research suggested that only very small incremental changes affecting the stitch length are needed to create a graduated profile. It was also noted that the higher the elastane count used, the less frequently it was needed in the structure to achieve the Sigel profile. Suggest by AES1 with the elastane every 4 courses.

Brand AES1's composition contravened legal requirements of +/-3% of the fibre content listed by the manufacturer and is essentially illegal on the marketplace.

Each Brand used completely different structures, consequently achieving significantly different pressure profiles. AES1 and AES3 exerted the greatest pressure at position B instead of A and therefore were not producing a normal gradient profile and would not be as effective as AES2.

It is clear that the measurement points are critical to the effectiveness of the treatment of AES and also from a product development view, as some of the results here are potentially alarming. The British Standard BS7672 only stipulates 2 measurement points – ankle and calf, and had these only been tested, all products would have shown a gradient profile. However, it is clear that there is an issue with AES1 and AES3 not exerting the expected gradient profile and having a peak in pressure at point B.

## Future Work

Further measurement of ideal pressure profiles across the manufacturers guidelines at both minimum and maximum circumferences.

Ultimately striving to achieve a global testing standard to ensure that we are all comparing like with like, as the current process is abundant with flaws and ambiguity.

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