

## DEVELOPMENT OF A COMPRESSIONAL BANDAGE FOR PROSPECTIVE USE BY PATIENTS

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### Abstract

The purpose of this research was to develop a short stretch weft knitted compression bandage that increases the venous flow of blood through the venous system without causing discomfort to the patient. Data collected showed that bandages in the Zimbabwean market for treating varicose veins exert high resting pressure and low working pressure resulting in an increase in the healing time. The bandages used for treatment of varicose veins must exert high working pressure in order to provide enough compression to reduce the diameter of the veins, thereby increasing the blood flow velocity reducing oedema. The bandage should also be comfortably when worn by patients in a resting position. A short stretch bandage with a blend of lycra and cotton yarns was developed on a V-bed weft knitting machine. The stitch notation was varied by use of full factorial experimental design to give optimum bandage pressure profile. Tests were carried out using a Tensometric machine to measure the pressure profile of the bandage. The tests showed that the compression bandage had the desired pressure profile for reducing oedema. The compression bandage was put on trial with selected patients and their healing process monitored. Questionnaires and assessment of patients during their regular check-up was made to track effectiveness of the bandage. Based on these trials it was concluded that the proposed bandage accelerates the healing process and had improved comfort properties.

**Keywords:** Compression bandage, Varicose veins, Venous ulceration, Pressure profile

### 1. INTRODUCTION

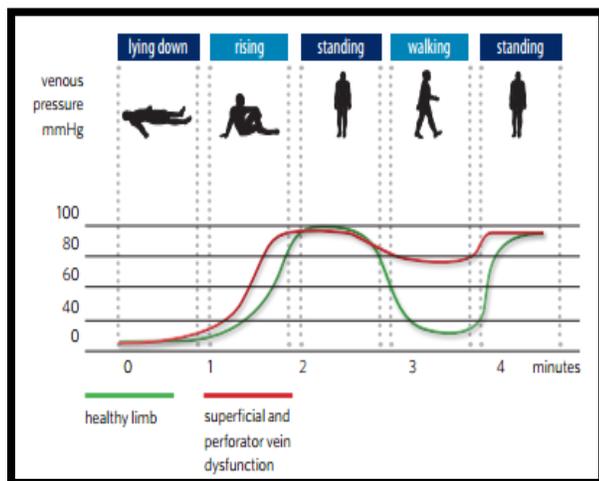
Compression treatment has been used to cure patients who suffer from accumulation of fluids on their limbs, poor blood circulation, varicose veins, venous ulceration, sprains, strains and lymphedema (Jacqui Fletcher and Christine Moffatt 2013). This treatment should be conducted through the application of bandages that exert compression without compromising the required healing pressure when active or resting. The aims of treatment are to reduce blood pressure in the superficial venous system; aid venous blood return to the heart by increasing the velocity of flow in deep veins; and reduce oedema by reducing the pressure differences between capillaries and tissue (Clare Williams 2002). Although the exact etiology of venous ulcers is poorly understood,

it is known that ulceration is more commonly found in women and the prevalence of ulcers increases with advancing age (Harley J et al 2004).

In Zimbabwe however, not much research has been conducted to investigate the properties of the compression bandages in use that can contribute to a comfortable process of healing. Preliminary data from the two Bulawayo hospitals have shown that over 90% of the patients use one kind of bandage (the long stretch compression bandage) which is locally manufactured hence readily available. This does not provide healing within the specified time. This research therefore aims at developing a bandage that will enhance the healing process and is comfortable to use when one is both active and resting.

Compression bandages currently available in the Zimbabwe market are long stretch compression bandages which are not suitable for treatment of varicose veins (Joachim E.Zuther et al 2013). Literature has shown that long stretch compression bandages have some shortcomings when worn at night and continuously for prolonged periods. For instance, they tend to cause necrosis (tissue damage) due to their high resting pressure. This reduces the body's ability to create positive blood flow towards the heart and a reflux may result in swelling of the limb. Reduction in the ability of the body to create positive flow of blood is a major drawback of long stretch compression bandage as the patient will need to remove the bandage at night, leading to an increase in the duration of treatment (Patricia Gilbert 1987). In a person at rest, normal venous pressure in the lower limb is mainly determined by the vertical distance between the ankle and the heart (Lisa MacGregor, 2013).

Figure 1 shows the variations of venous pressure relative to the position of the patient.



**Figure 1 – Changes in pressure measured at ankle in venous system in legs for healthy and defective venous valves during lying, rising, standing and exercise (Robyn Bjork 2013).**

### 1.1 Description of the Related Bandages

There are three main types of compression bandages the long stretch compression bandages stretch to approximately 140% to 300% of their original length (Vowden K and Vowden P 2012), short stretch bandages which stretch up to about 30% to 60% of their original length (Vowden K and Vowden P 2012), and the compression stockings (made to fit). The compression stockings are different from the long stretch and short stretch compression bandages in that they come fully fashioned and are worn just like normal stockings. Long stretch bandages can be applied over large areas, like a portion of the limb. These bandages apply pressure over the affected area and have a high resting pressure and are usually removed when the body is at rest to prevent discomfort when the patient is asleep which retards the healing process (Compression Bandages and their use n.d.). The short stretch bandage is known to have comfort properties as required by patients. However, this is hardly available in the Zimbabwean market.

Compression stockings are easier to fit, but apply less pressure than bandages. Because they are manufactured in a tubular form, there are limitations in varying the diameter of the stocking, making it difficult to produce a specific pressure profile. The pressure applied is also a function of the fabric tension and the curvature of the leg, so the same stocking will produce a different pressure profile in different patients (Scan to knit n.d.).

The aim of the study was to develop a short stretch compression bandage for Zimbabwe that increases the venous flow of blood through the venous system without causing discomfort; exerts the optimum pressure for the treatment of sprains, strains, varicose veins and venous ulceration. Further we intended to identify the shortcomings of the compression bandages currently on the market.

## 2.0 METHODOLOGY

A short stretch compression bandage was designed and developed on a JF flat knitting machine. The bandage was tested on a Tensometric machine manufactured by SDL ATLAS (Serial No. 24469) to establish the pressure profile of the bandage. The bandage that provided suitable pressure was then tested on patients who suffered from varicose veins and venous ulceration.

Fifteen purposefully selected participants comprising of 12 females and 3 males, receiving physiotherapy treatment for varicose veins at a hospital in Bulawayo were issued with bandages that were applied by the nursing staff and subsequently by the patients themselves after receiving training on how to apply the bandages. The patients were selected because they had been diagnosed with varicose veins. The patients consented to take part in the research by filling out and signing an informed consent form.

The patients were requested through a questionnaire to report on the properties of the bandage such as reduction of swelling, slippage of bandage, comfort during day and night, ease of application, and discomfort due to bandage application. They were also asked to suggest improvements that can be made to enhance comfort properties of the bandage. The bandage was applied to different parts of the leg such as thigh to calf, knee to calf and calf only for the different patients depending on location of the varicose veins.

### 3.1 Ethical Considerations

Permission was sought and obtained from Medical Research Council of Zimbabwe to carry out research trials on patients in the country. Further permission was obtained from the PMD of the respective region for testing of patients in the hospital. At the hospital permission for carrying out the research was sought from the Nursing officer and approved by the Executive Officer of the hospital.

## 3.2 Development of the Short Stretch Compression Bandage

The short stretch compression bandage was designed on a JF series flat bed weft knitting machine. The machine is a non-jacquard machine and utilizes needle butt selection to obtain the required structure.

A simple 3X3 full factorial experimental design was used to ascertain the effect of different machine settings on the pressure profile of the short stretch compression bandage. Full factorial experimental designs are most useful where the number of factors is relatively limited. An N factor, K level design involves  $K^N$  experiments. Three levels were used and the three factors were stitch notation, stitch length, percentage lycra in the bandage. The levels used for stitch notation were knit, tuck and miss. For stitch length, and lycra content values were set as shown in table 1.

**Table 1 - Levels of the independent variables  $X_i$  in the 3 level, 4 factor experimental design of experiments**

Variable	Definition	Levels		
		1	0	-1
$X_1$	Stitch Notation	Knit	Tuck	Miss
$X_2$	Stitch Length (mm)	8	9	10
$X_3$	Percentage Lycra	2.5%	5%	8%

### 3.3 Yarns

The counts of lycra and cotton were varied systematically to obtain the best results. Blend ratio was varied in order to increase or decrease the elastic properties and hence alter the pressure profile of the bandage. The yarn

used was 23 tex combed cotton. Combed yarn was used in order to have fine and fluff free bandage. 1/70 den nylon lycra natural was used as the elastomeric yarn to impart the designed stretch and pressure profile to the bandage. The feed system used contained two cones of 23 tex cotton combed cotton yarn and one feed of 1/70 den nylon lycra plaited through a single feed.

**3.4 Fabric Structure**

Several fabric structures were tried out based on the spacer fabric principle and use of full factorial experimental design. The spacer fabric principle incorporates a tubular structure into fabric structure. A combination of different type of stitches such as tubular structure and 1X1 rib structure was used to give the fabric a soft feel. To control the weft wise direction, stretch the tubular structure was limited to only two courses per repeat of which the repeat consisted of 6 courses. Stitch length and machine gauge were varied systematically by means of choosing gauge and stitch length and then carrying out pressure profile tests on Tensometric tensile tester machine, to arrive at a fabric with good handle properties and optimum pressure profile.

Needle set out was systematically varied by varying set out of needles and putting some needles out of action in order to come out with the most suitable handle of the fabric. The needle set out which was then selected involved all needles in action in alternating long and short butt set out. In order to produce the required specification of short stretch compression bandage the yarn feeding system had to be modified from the normal feed system that only takes cotton and non-elastomeric yarns. The lycra was introduced into the same feeder as the cotton feed system inducing small amount of twist between the cotton and lycra due to yarn uptake and hence allowing cotton and the fine lycra to be fed simultaneously.

**3.5 Bandage production specifications**

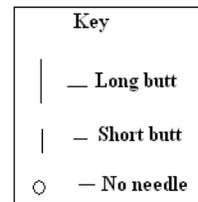
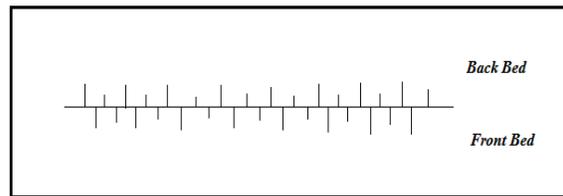
Table 2 shows some of the essential quality settings of the machine to produce the desired short stretch compression bandage.

**Table 2 – Quality Settings of flat machine**

SETTING	VALUE
Economizer	Continuous fabric
Fabric Width	5cm/10cm/15cm
Total No. of needles	53/106/159
No. of courses/3cm	28
No. of wales/3cm	19
Take down weight (kg)	0.25
Machine speed	1 transverse/2.2 sec

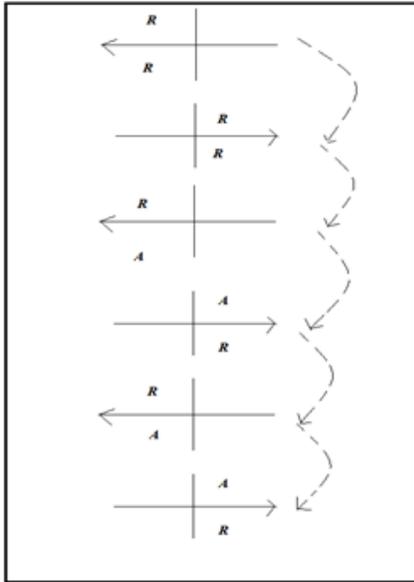
**3.6 Knitting Notations**

The machine used was a JF Series 14-gauge Flat weft knitting machine. The needle set out was alternate long and short butt needles. The machine was set to rib gating.



**Figure 2 – Needle set diagram**

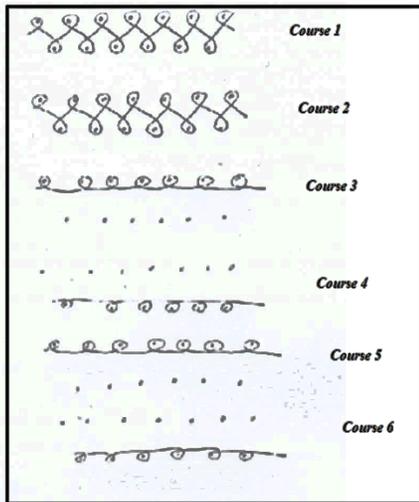
The knitting notation used included alternate tubular structures and 1X1 rib. Figure 2 shows the knitting notation. The machine used single carriage with single cam system.



**Key**

**KEY**  
*R - All needles knitting*  
*A - Cam out of action*

**Figure 3 – Machine Knitting Notation**



**Figure 4 – Knitting notation**

The yarn feeding system used a single cam system with 1 lycra end of 1/70Den and two cotton ends of 23tex cotton combed yarn.

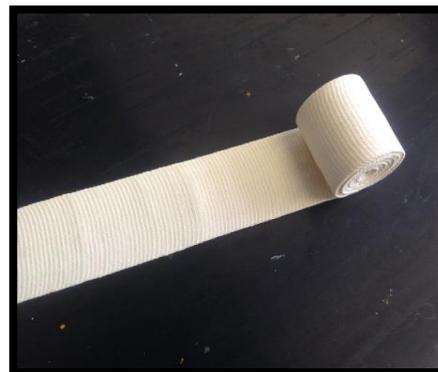
**3.6.1 Bandage Samples:** Figure 3(a) to 3(c) show the different widths of compression bandages produced (15cm/10cm/5cm).



**a) Bandage width 15cm**



**b) Bandage width 10cm**



**c) Bandage width 5cm**

**Figure 5 - Proposed short stretch compression bandages**

### 3.7 Pressure Profile of bandages

The pressure profile of the compression bandages was measured using the Tensometric machine manufactured by SDL ATLAS (Serial No. 24469). The type of the machine is model DBBMTCL. The machine had jaws and clamps that gripped the compression bandages firmly. The sample lengths used were 200mm and the test speed was 200mm/min. The pretension added was 10kgf. For every sample of compression bandage four tests were carried out and the load-extension graph plotted.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Patients Perspective

The results from the questionnaires issued to patient participants showed that the bandage was favoured by all 15 participants. They all indicated that it helped in the reduction of swelling and did not cause pain or discomfort in any position. The participants did not have any problems with the bandage slipping during day time activities. They did not need to reapply it.

The participants were able to sleep with the bandage on without it causing any undue discomfort. The bandage proved easy to apply for participants after they had been shown how to correctly apply it. Most of the participants were suffering from varicose veins at different areas of the leg. Ten of the patients had varicose veins starting from the top of the leg running down to the calf. The other five had varicose veins from the calf to the ankle region.

None of the patients who used the bandage complained of the bandage digging into the flesh as long as it had been correctly applied.

### 4.2 Health personnel perspective

The nursing officer applying the bandages asked the patients during reviews if the bandage was comfortable and all participants were comfortable with the bandage. The major reason for bandage change was routine change. The nursing officer did not report any indication of excessive pressure due to the bandage on the participants. The nursing

officer reported that bandage was fairly easy to apply

Participants did not complain of any tingling sensations on limb at any position (sitting, standing, and sleeping) due to the bandage which would have been indicative of excessive pressure. There was no noticeable change in colour on the affected limb due to the bandage which would also have been a sign of excessive pressure.

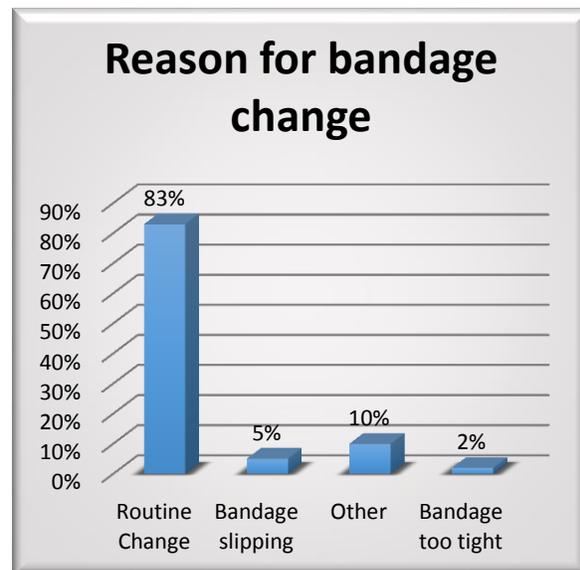


Figure 6 – Reason for bandage change

The nursing officers commented that as long as the bandage was applied correctly no severe lines or marks due to excessive pressure of bandage should be present on the affected limb. The nursing officer also said that the bandage should be available in varying widths for ease of application. This suggestion was noted and additional bandages were produced in different widths. The main reason for bandage change in 83% of the instances was during routine checkup as indicated in Figure 5. Ten percent of the patients removed the bandage for various other reasons including that the bandage would be dirty. Two patients claimed that they removed the bandage as it was tight but on investigation it was noted that wrong method of application of the bandage was being followed by the patients.

**4.3 Sub Bandage Pressure**

Pierre Simon Laplace described a formula that defined the pressures exerted on curved surfaces (Pellicer et al 2000) a challenge with this formula was that it did not take into account the adaptations that occur in the human leg which has neither a solid nor constant curved surface. Thomas then made a modification to the original Laplace equation to take into account the width of the bandage and the number of layers applied. The modified equation is referred to as the Laplace’s law (Thomas S 2003).

Thus to calculate the pressure that the compression bandage is able to produce while the patient is at rest and while the patient is standing the Laplace formula for sub bandage pressure was used. According to Laplace’s law, sub-bandage pressure is directly proportional to bandage tension, but inversely proportional to the radius of curvature of the limb to which it is applied. In the case of sub-bandage pressure, the equation is conveniently expressed as follows,

$$\text{Pressure (mmHg)} = \frac{\text{Tension(Kgf)} \times n \times 4620}{\text{Circumference(cm)} \times \text{Bandage width (cm)}} \quad [1]$$

(Thomas S 2003)

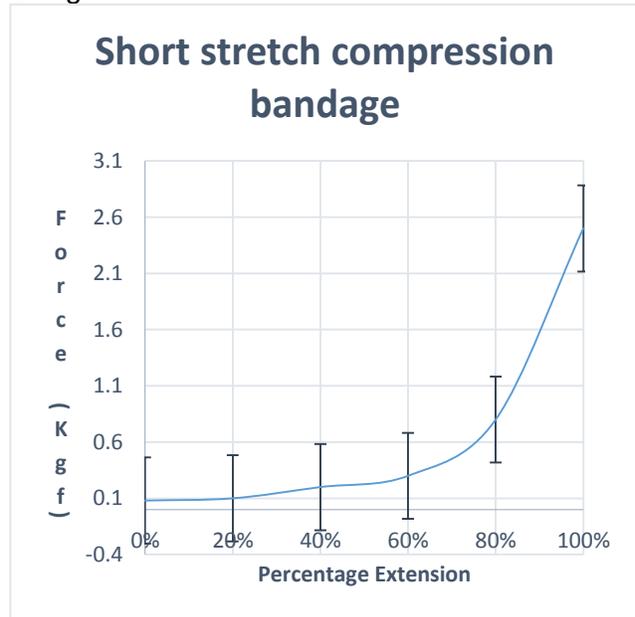
“Where”, *n*= is the number of bandage layers applied and 4620 a constant

**4.4 Comparison of pressure profile of the new short stretch compression bandage and the long stretch compression bandage found in the market**

**4.4.1 Pressure Profile of the short stretch compression bandage**

The short stretch compression bandage has a low resting pressure and high working pressure as shown by the graph in Figure 5. When the bandage is at full stretch at 100% the force exerted is very high at 2.5Kgf (working pressure). Figure 5 shows that at 0% extension the bandage exerts 0.1 kgf force. From extension of 0% to about 20% extension of the bandage the force exerted by the bandage is almost constant; there is just a slight increase of

0.1kgf.



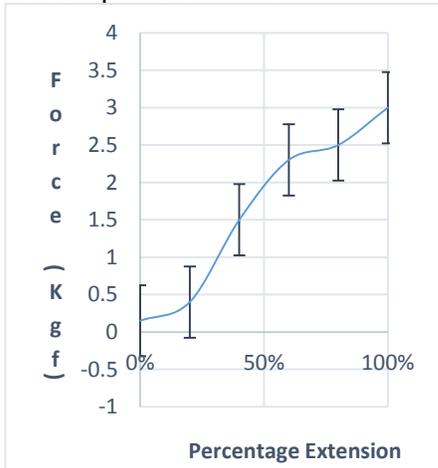
**Figure 7 – Proposed short stretch compression bandage with a 10cm width.**

This means that when the limb size decreases and the patient is in a supine position the extension of the bandage reduces due to decrease in limb diameter and the force applied correspondingly reduces. With just a reduction of extension of 10% from 100% extension the exerted force by the bandage falls from 2.5Kgf to 1.50kgf. The major working area of the bandage is between 80%-100% extension. The fact that this bandage has a sharp reduction in force due to reduction in extension makes the bandage comfortable and safe to wear throughout the day and at night. In a resting position as the bandage diameter also reduces the amount of the bandage is said to have a low resting pressure.

The limited stretch of the bandage makes the bandage useful as a strapping preventing the limb which the bandage is applied to, from going beyond its normal range of movement. This is useful in contact sports as a prevention of sprains and strains.

**4.4.2 Pressure Profile of the long stretch compression warp knit bandage**

The long stretch compression bandage mainly used by patients Figure 6, has a high resting pressure of above 2,5kgf at 80% extension. The warp structure is used so as to control the magnitude of stretch which if uncontrolled might destroy the whole purpose of the bandage. The bandage might slide away from the area being treated, as it will not have adequate compression force.



**Figure 8 - Warp Knit long stretch compression bandage**

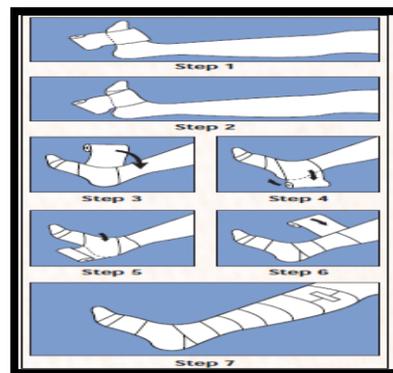
When the bandage is at full stretch of 100% it exerts a force of 3Kgf (working pressure). However, because this bandage has high resting pressure it is not applied at full stretch as it would exert an undesirably high resting pressure. When the limb diameter of patient decreases such as when a patient is in a supine position the corresponding reduction in pressure is small. In the graph for a reduction in 20% in extension from 80% to 60% there is only 0.1Kgf reduction in pressure applied. This makes the bandage uncomfortable to wear when patient is in a resting position and hence some patients opt to remove the bandage which increases the duration of the healing time in the process. The greatest oedema reduction occurs in the first week of treatment. The exact length of compression bandage treatment duration will vary with individual patient characteristics between 1 to 4 weeks (Deborah Glover 2012).

**4.5 Application of Bandage**

The Laplace equation is used to calculate the pressure that the compression bandage exerts (Deborah Glover 2012). Correct pressure of the compression bandage is obtained when the bandage is correctly applied on the limb. Steps of correct application of the bandage are as shown in Figure 7.

The short stretch compression bandage must be applied in a spiral manner from the inside of the limb to the outside. Bandaging must begin from the ankle using two turns to secure the bandage. Bandaging is continued up the leg in a spiral, at full 100% stretch with 50% overlap. Any excess bandage must then be cut off and the bandage secured.

Unlike stockings or tubular bandages, where the relationship between extension (a function of limb diameter) and fabric tension is 'pre-programmed' into the product during the manufacturing process, the tension developed in most flat bandages during application is determined entirely by the operator (Steve Thomas 2003). Studies have shown that the tension with which bandages are applied by different nurses varies significantly from person to person, although the pressure achieved by individuals following repeated application of a bandage is much more consistent (Steve Thomas 2003). Although bandage tension, and hence sub-bandage pressure, is initially determined by the user during application, the ability of a bandage to maintain this tension, is subsequently determined by its elastomeric properties (Nelson E.A 1996).



**Figure 9 – The steps of correct application of the short stretch compression bandage (Stemmer et al 1980).**

## 5.0 CONCLUSION

A short stretch compression bandage was successfully produced on a JF Series flat weft knitting machine. This bandage had a pressure profile that enabled it to be worn throughout the day with good comfort properties that were acceptable to patients and it accelerated the healing rate. The bandage properties can be improved if a better feed system attachment unit for fine lycra yarn can be incorporated into the V bed flat knitting machine for positive control of yarn feed.

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