Technical note

The pressure exerted by an elastic stocking and its measurement

Keywords—Elastic stocking pressure measurement

Introduction

Elastic stockings used to relieve the undesirable effects of varicose veins are required to provide a pressure on the skin which gradually increases towards the lower part of the leg. Ideally, such a stocking should exercise a radial pressure compensating the static pressure of blood in the veins which develops when the patient is standing.

In an elastic stocking the radial pressure is produced by the tension in the elastic fibres of the stocking fabric. The degree to which this tension is transformed into a radial force unfortunately depends on the curvature of the leg surface. The use of a 'tight' stocking (i.e. a stocking with high peripheral tension) therefore by no means guarantees that the desired radial pressure will be attained.

Measuring methods presently available are either rather inaccurate or—in order to measure the tensile characteristics of the fabric—require cutting the stocking into stripes; i.e. the sample is destroyed. As a consequence the medical doctor prescribing an elastic stocking has no practical means to check its performance, and with the expansion of vascular diseases in developed societies, an increasing number of patients use a prosthetic device the effect of which is uncertain.

In the first part of this paper a simple theory is presented which should lead to a better understanding of the basic principles of function of an elastic bandage. In the second part a device is described with which it is possible to measure the pressure exerted at any chosen point of the leg surface without upsetting the original adjustment of the bandage. A measurement example indicates the importance of a correct selection and adjustment of the stocking.

Calculation of radial pressure

Let us assume a simplified model with a circular cross-section and no longitudinal curvature (i.e. a cylindrical body). We assume that there is no friction between the stocking and the surface of the cylinder so that the peripheral tension is everywhere the same.

We use the following symbols:

\[ R \] radius of the cylinder, cm

\[ T_p \] peripheral tension at the cross section for one cm width of fabric, g/cm

\[ \Delta x \] angle subtended at the centre of curvature of a small peripheral segment \( \Delta x R \), rad

The radial force \( P_r \), exerted by a 1 cm-wide strip of fabric may be calculated from Fig. 1 as:

\[ P_r = T_p \sin \frac{\Delta x}{2} \text{ [g, rad]} \]

and the radial pressure per square centimetre:

\[ \frac{P_r}{S} = \frac{2T_p \sin (\Delta x/2)}{\Delta x \cdot R} \text{ [g/cm}^2, \text{g, rad, cm]} \]

where \( S = \Delta x R \times 1 \text{ cm} \) is the area of the 1 cm-wide strip subtended by the angle \( \Delta x \).

For small angles

\[ \sin \frac{\Delta x}{2} \approx \frac{\Delta x}{2}, \]

and hence:

\[ P_r \approx \frac{T_p}{R} \text{ [g/cm}^2, \text{g, cm]} \]

\[ \text{(1)} \]

The radial pressure per square centimetre exerted by an elastic stocking on the surface of a cylindrical body is therefore proportional to the peripheral tension of a

\[ \text{Fig. 1 Radial force exerted by a strip of elastic fabric} \]

\[ \text{Fig. 2 Pressure profiles at cross-sections of different shape} \]

Solid line designates outline of cross-section; width of cross-hatched area normal to tangent at a chosen point designates the relative pressure at that point (Fig. 2C)
1 cm-wide strip of fabric divided by the radius in centimetres of the curvature at the area considered.

In the special case of a cylinder with circular cross-section the pressure is everywhere the same and equal to \( p_r = T_p/R \) (Fig. 2A). Distributions of pressure around the perimeter of cross-sections where the radius of curvature changes between \( R_{\text{max}} \) and \( R_{\text{min}} \) are shown in Figs. 2B and 2C.

It may be seen that radial pressure may be exerted only on convex surfaces. If the surface is plane or concave the stocking cannot exert pressure.

**Practical pressure profiles at a cross-section of the leg**

The actual curvature of the leg surface is 2-dimensional, and hence the pressure exerted by an elastic stocking is the result of both the peripheral as well as the longitudinal tension in the stocking fabric. The pressure due to longitudinal tension \( T_L \) may be calculated in the same way as has been done for the peripheral tension:

\[
p'_{r} \approx \frac{T_L}{R_L}
\]

The total pressure therefore approximately equals

\[
p = p_r + p'_{r} = \frac{T_p}{R} + \frac{T_L}{R_L}
\]

In practice, except around the ankles, the radius of the longitudinal curvature \( R_L \) is much larger than the cross-sectional radius \( R \), and the longitudinal tension \( T_L \) is less than \( T_p \), so that \( p'_{r} \ll p_r \). The approximate pressure may thus be calculated directly from eqn. 1.

In Fig. 3A is a diagram of the pressure distribution which a chosen elastic stocking exerts on a typical leg about 10 cm above the ankle.

Fig. 3B shows the effect of the same stocking at the ankle as calculated with the help of eqn. 3 using data obtained from direct measurement of both cross-sectional and longitudinal curvatures of the leg.

In both calculations the peripheral tension in the stocking has been assumed to be the same around the whole perimeter in question, while the longitudinal tension at all significant locations has been taken into account.

**Measurement of pressure profiles**

The peripheral and longitudinal tensions depend on the size and type of stocking as well as on the degree it is stretched vertically when it is put on. It is difficult to ensure the correct vertical pressure gradient without some measurements of pressure. Until recently no such measurements could be made without cutting the fabric. A simple device which is presently in an experimental stage is shown in Fig. 4 (patent applied for). It consists of a sensitive pressure switch in a thin-walled rubber pocket connected by a flexible tube to a pressure gauge used by doctors to measure blood pressures.

![Fig. 4 An experimental pressure gauge to measure the pressure exerted by an elastic bandage](image)

A Rubber pocket with pressure switch
B Insertion tool

![Fig. 3 Pressure exerted by an elastic stocking around the cross-section of a leg at various heights above ankle](image)

![Fig. 5 Longitudinal (vertical) profile of pressure exerted by a stocking on the front of a leg up to a height of 35 cm above ankle](image)