A Bandage Squeezes Hardest Where the Leg Is Thinnest, a Stretch Tube Where It Is Thickest

— A bandage wound at constant tension squeezes a **22** cm ankle **1.636364** times as hard as a **36** cm calf — to make a tube squeeze the ankle harder, the calf must be knitted to a different circumference, **28.6957** cm —

[Paper 583]

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September 2026

— From thinking to syncing. —

Abstract

Leg bandages and compression stockings are explained by the Laplace formula $P = T/r$: where the leg is thinner the radius is smaller, so at the same tension it is squeezed harder.What this paper shows is that this holds for a bandage, whose tension is fixed by how it is wound, but not for a tube whose tension is fixed by how far it is stretched, and that a tube knitted straight squeezes hardest where the leg is thickest.No new theorem or law is claimed. First, the pressure of a fabric wrapped round a leg is $P = 2\pi T/C$——T is the tension per unit width and C the circumference (Section 1). **Second, at constant tension, the thinner part is squeezed harder——a bandage wound at 100 N/m gives 21.4218 mmHg at the ankle and 13.0911 mmHg at the calf, a ratio equal to the inverse ratio of circumferences, 1.636364** (Section 2). **Third, and this is the core.In a tube whose tension is set by stretch, the direction reverses——a tube knitted straight at 20 cm is stretched 0.1 at the ankle for 6.4265 mmHg and 0.8 at the calf for 31.4186 mmHg, squeezing the calf 4.888889 times as hard** (Section 3). **Fourth, the pressure of a stretch tube always rises with circumference——$P = 2\pi K(1/C_0 - 1/C)$, so $dP/dC = 2\pi K/C^2 > 0$** (Section 3). **Fifth, a tube that squeezes the ankle harder must be knitted to different circumferences along the leg——knitting the ankle at 18 cm for 14.2812 mmHg, the calf must be knitted at 28.6957 cm to receive seven tenths of it; the ratio of the tube's circumferences, 1.594203, is a little smaller than the leg's, 1.636364** (Section 4). **Sixth, the separator is whether the tension is set by winding or by stretch——the same formula makes opposite gradients according to where the tension comes from** (Section 5). **Keywords**: elastic bandage, compression, Laplace's law, tension, compression stockings.

Scope of this paper (scope note): No new theorem or law is claimed——the Laplace formula for a membrane and a linear relation between stretch and tension are standard.The leg is a cylinder——a real leg is not round; over bony prominences the curvature is large and the pressure varies from place to place.The fabric stretches linearly——real knitted fabric has a curved relation between stretch and tension, different on putting on and taking off.The numbers are representative——an ankle circumference of 22 cm, a calf of 36 cm, a bandage tension of 100 N/m per unit width and a tube stiffness of 300 N/m per unit stretch.Slip and friction are not included.No medical advice is given and no product is recommended——which pressure is good, and who should wear what, is not stated.Relation to earlier papers: Paper 309 showed the length that divides gravity from surface tension, using the Laplace pressure——surface tension does not change however far a film is spread, the same type as the bandage here; a stretch tube is a different type, whose tension itself changes with stretch.Paper 300 showed that sharing a root is decidable——bandage and tube come from the same $P = T/r$, but because their tension comes from different places, their gradients point opposite ways.What is added is comparing on one leg a bandage at constant tension and a tube whose tension is set by stretch, and checking against closed forms that their gradients point opposite ways, showing that the pressure of a stretch tube rises monotonically with circumference, finding the knitted circumference needed for a tube that squeezes the ankle harder, and showing that its ratio of **1.594203** is smaller than the leg's, and placing the separator on where the tension comes from.

1. Notation and the Question

Setting: when a fabric is wrapped round a leg of circumference C (radius $r = C/2\pi$) at a tension T per unit width, the pressure on the leg follows from the Laplace formula

$$P = \frac{T}{r} = \frac{2\pi T}{C}.$$

In a tube whose tension is set by stretch, with relaxed circumference C_0 and stiffness K per unit stretch, $T = K(C - C_0)/C_0$ and

$$P = 2\pi K \left(\frac{1}{C_0} - \frac{1}{C} \right).$$

Observation 1.1

compression is explained by the Laplace formula.Where the leg is thinner the radius is smaller, so at the same tension it is squeezed harder; hence a uniform fabric made into a tube is said to give "graduated compression", firm at the ankle and gentle at the calf——the explanation silently assumes that the tension is the same everywhere.

Question: **when the tension is not constant, what does the same formula say?**

2. At Constant Tension

Computation 2.1: **a bandage wound at a constant 100 N/m per unit width.**

place	circumference	pressure
ankle	**22** cm	**21.4218** mmHg
calf	**36** cm	**13.0911** mmHg
ratio		**1.636364**

> **Observation 2.2**
>
> **at constant tension, the thinner part is squeezed harder.The ratio matches the inverse ratio of circumferences, $36/22$, to 10^{-12}——as long as the person winding pulls with the same force, the ankle is pressed harder. This is the proper range of the "graduated compression" explanation.**

3. When Stretch Sets the Tension

Computation 3.1: **a tube knitted straight at 20 cm (stiffness 300 N/m per unit stretch) on the same leg.**

place	circumference	stretch	pressure
ankle	**22** cm	**0.1000**	**6.4265** mmHg
calf	**36** cm	**0.8000**	**31.4186** mmHg
calf / ankle			**4.888889**

> **Observation 3.2**
>
> **this is the core.A stretch tube knitted straight squeezes the thick calf 4.888889 times as hard——the ratio matches the closed form $(1/20 - 1/36)/(1/20 - 1/22)$ to 10^{-12}. The thicker the leg, the more the tube stretches and the higher its tension, and that rise outweighs the fall in pressure from the larger radius.**

Observation 3.3

the pressure of a stretch tube always rises with circumference.$dP/dC = 2\pi K/C^2$ is positive——whatever stiffness and relaxed circumference are chosen, a uniform tube squeezes thicker parts harder. “A uniform fabric made into a tube gives graduated compression” does not hold for a stretch tube.

4. A Tube That Squeezes the Ankle

Computation 4.1: **the ankle knitted at 18 cm, and the calf’s knitted circumference solved so that the calf receives seven tenths of the ankle’s pressure.**

quantity	value
ankle pressure (knitted at 18 cm)	**14.2812** mmHg
knitted circumference needed at the calf	**28.6957** cm
ratio of the tube’s circumferences	**1.594203**
ratio of the leg’s circumferences	**1.636364**

Observation 4.2

at that circumference the calf returns exactly to seven tenths (to 10^{-12}).A tube that squeezes the ankle harder can only be made by varying the knitted circumference along the leg——and the tube’s ratio of 1.594203 is a little smaller than the leg’s 1.636364. Following the leg’s shape is not enough; the calf must be knitted slightly tighter.

5. The Separator

Observation 5.1

the separator is whether the tension is set by winding or by stretch.In a bandage whose tension is set by winding, the tension does not depend on place, and thinner parts are squeezed harder——in a tube whose tension is set by stretch, the tension rises where the leg is thicker, and thicker parts are squeezed harder. The same $P = T/r$ makes opposite gradients according to where the tension comes from.

Observation 5.2

the surface tension of Paper 309 is the bandage type.It showed the length that divides gravity from surface tension, using the Laplace pressure——surface tension does not change however far a film is spread, so the pressure is higher where the curvature is sharper. A stretch tube is a different type, whose tension itself changes with stretch.

Observation 5.3

under Paper 300, two uses of one formula.Bandage and tube both come from $P = T/r$——what differs is where T comes from, and there the direction of the gradient splits. The same formula with different quantities put into it gives opposite conclusions.

Observation 5.4

what is not said.No medical advice is given and no product is recommended——what is shown is only under which kind of tension “the thinner part is squeezed harder” holds, and under which it reverses.

6. Roll Call and Closing

1. **pressure $P = 2\pi T/C$** (Notation): **the Laplace formula.**
2. **bandage: ankle 21.4218, calf 13.0911 mmHg** (Computation 2.1): **a ratio of 1.636364.**
3. **the ratio equals the inverse ratio of circumferences** (Observation 2.2): **the proper range of constant tension.**
4. **tube: ankle 6.4265, calf 31.4186 mmHg** (Computation 3.1): **the direction reverses.**

5. **the calf 4.888889 times** (Observation 3.2): **the core.**
6. $dP/dC > 0$ (Observation 3.3): **a uniform tube squeezes thicker parts harder.**
7. **ankle knitted at 18 cm gives 14.2812 mmHg** (Computation 4.1): **the starting point of graded knitting.**
8. **the calf knitted at 28.6957 cm** (Computation 4.1): **the circumference for seven tenths.**
9. **tube ratio 1.594203 below leg ratio 1.636364** (Observation 4.2): **following the shape is not enough.**
10. **the separator is where the tension comes from** (Observation 5.1): **winding or stretch.**

Closing: **Leg bandages and compression stockings are explained by the Laplace formula $P = T/r$: the thinner the leg, the harder the squeeze.That holds for a bandage, whose tension is fixed by how it is wound——wound at 100 N/m per unit width, it gives 21.4218 mmHg at a 22 cm ankle and 13.0911 mmHg at a 36 cm calf, a ratio equal to the inverse ratio of circumferences, 1.636364.In a tube whose tension is set by stretch, the direction reverses——a tube knitted straight at 20 cm gives 6.4265 mmHg at the ankle and 31.4186 mmHg at the calf, squeezing the thick calf 4.888889 times as hard. Its pressure $P = 2\pi K(1/C_0 - 1/C)$ always rises with circumference, so a uniform tube, whatever its stiffness or relaxed size, squeezes thicker parts harder. A tube that squeezes the ankle harder must be knitted to different circumferences along the leg: with the ankle at 18 cm for 14.2812 mmHg, the calf must be knitted at 28.6957 cm for seven tenths, a ratio of 1.594203, smaller than the leg's 1.636364, so following the leg's shape is not enough.The separator is whether the tension is set by winding or by stretch——the same $P = T/r$ makes opposite gradients according to where the tension comes from; under Paper 300 bandage and tube are two uses of one formula.Placed among the earlier papers——the surface tension of Paper 309, unchanged however far a film is spread, is the same type as the bandage; a stretch tube is a different type, whose tension itself changes with stretch.To be honest——the leg was a cylinder, the fabric linear, and neither slip nor friction included; the numbers are representative. No medical advice and no product recommendation are given: what is shown is under which kind of tension "the thinner part is squeezed harder" holds, and under which it reverses.**

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