Design of Active Material Compression Stockings

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INTRODUCTION

Compression stockings are a common off the shelf garment that apply an evenly distributed pressure across the body for medical, athletic, and consumer purposes. The pressure provided by these garments vary, typically in the 8-40 mmHg range, depending on the intended end use. To provide the desired compression, the stockings are undersized relative to the body dimensions of the wearer [1]. Compression stockings on the higher end of the compression range are often difficult to don because they must be stretched over the body. Populations with limited upper body and grip strength find it difficult to don these garments leading to low compliance. To improve the donning experience, this research seeks to develop a compression stocking utilizing a custom shape memory alloy (SMA) material that transitions between low- and high-stress states according to the applied temperature. These materials can be spun with other fibers into a multifilament yarn and knit into an active textile (Figure 1) [2].

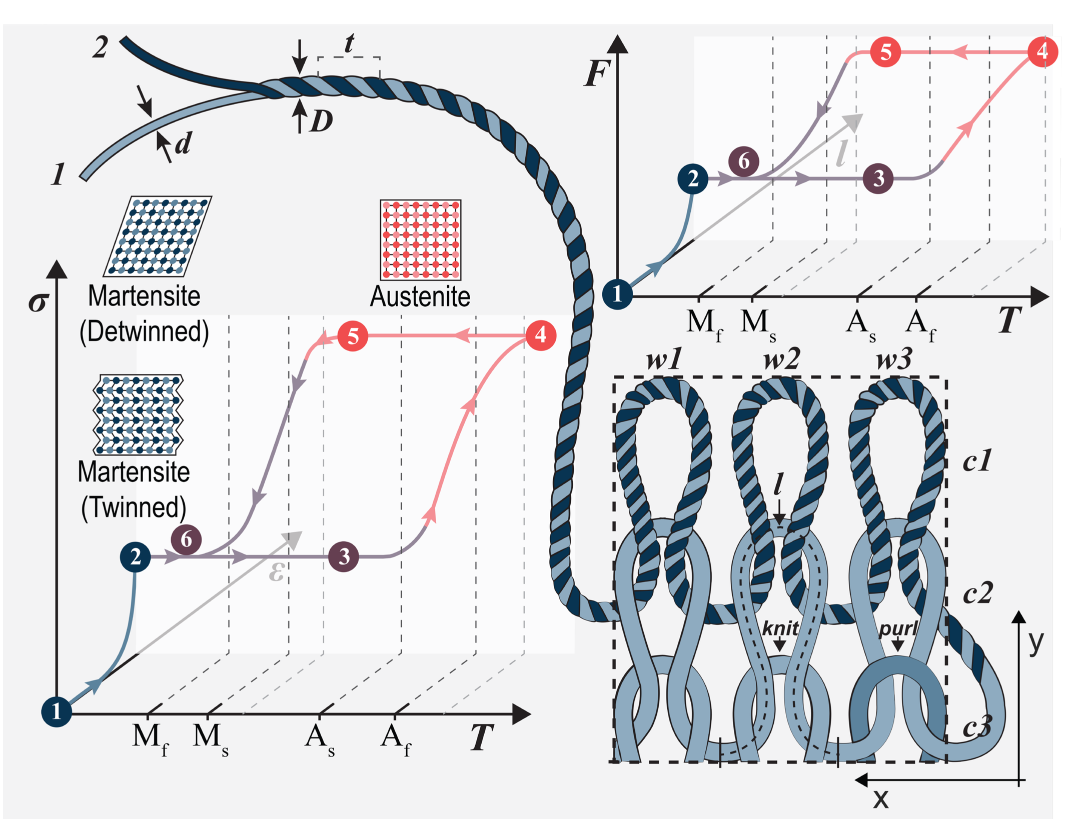

Figure 1. Shape memory alloys (SMA) accomplish large recovery stresses (σ) in a fixed strain (ε) state when increased temperatures (T) cause the material to transition from a martensite (less-stiff) to an austenite (more-stiff) state. SMA filaments are spun into yarns and reconfigured into knit textiles to produce and active textile that increases blocking force (F) upon an increase in temperature.

This active knit textile can then be integrated into a knit stocking that can be donned in a low-compression state and transition to a high-compression state upon application of a commercial heating pad (Figure 2).

METHODS

A prototype compression stocking spanning the foot to the low-knee was designed in a size 'medium' to accommodate a range of users. The range of cross-sectional circumferences that fall within a size 'medium' were determined through size charts for compression stockings currently on the market (Figure 3).

	Medium Compression Stocking Size Range
Knee	23 – 28 cm
Calf	21 – 24 cm
Ankle	34 – 40 cm
Foot	30 – 35 cm

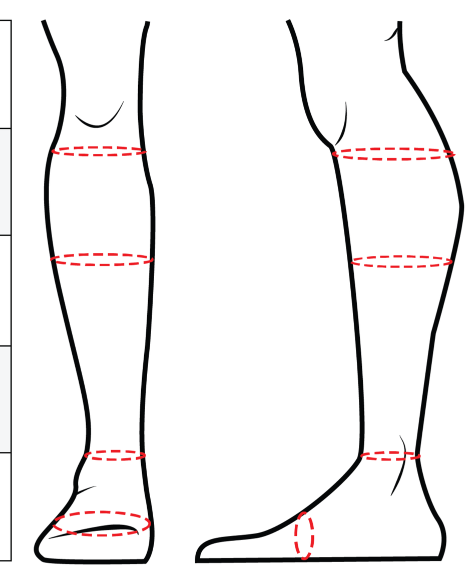

Figure 3. The compression stocking is designed to accommodate a range of individuals that fall within a size 'medium' category.

The garment pattern was developed using the Law of Laplace,

$$P\,[Pa] = \frac{t\,[\frac{N}{m}]}{R}$$

which relates circumferential pressure to unit tension (t), or force per unit width, of the stocking to body radius (R). Connecting an active textile to a passive textile in series enables the stocking to oscillate between low- and high-pressure states in response to the heating pad. Once the heating pad is removed, the stocking remains in a high-compression state indefinitely at natural body surface temperature without additional heat.

RESULTS

The garment design methods produce a compression stocking that exerts low, inactive pressure to facilitate donning (i.e., 10-15 mmHg) (Table I). When the commercial heating pad is applied, the stocking increases pressure to 25-30 mmHg. In addition to achieving a change in pressure, the design methods focused on stabilizing inactive and active pressures across the dimensional range to ensure that all size 'medium' users have a similar compression experience (Figure 4).

Table I. The stocking is designed to exert a 10-15 mmHg pressure range while inactive and increase pressure to a 25-30 mmHg range upon application of a commercial heating pad.

	Minimum circumference		Maximum circumference	
	Inactive pressure [mmHg]	Active pressure [mmHg]	Inactive pressure [mmHg]	Active pressure [mmHg]
Average	10	25	15	30
Low-knee	8	20	13	29
Calf	8	21	12	27
Ankle	11	30	19	32
Foot	11	30	21	42

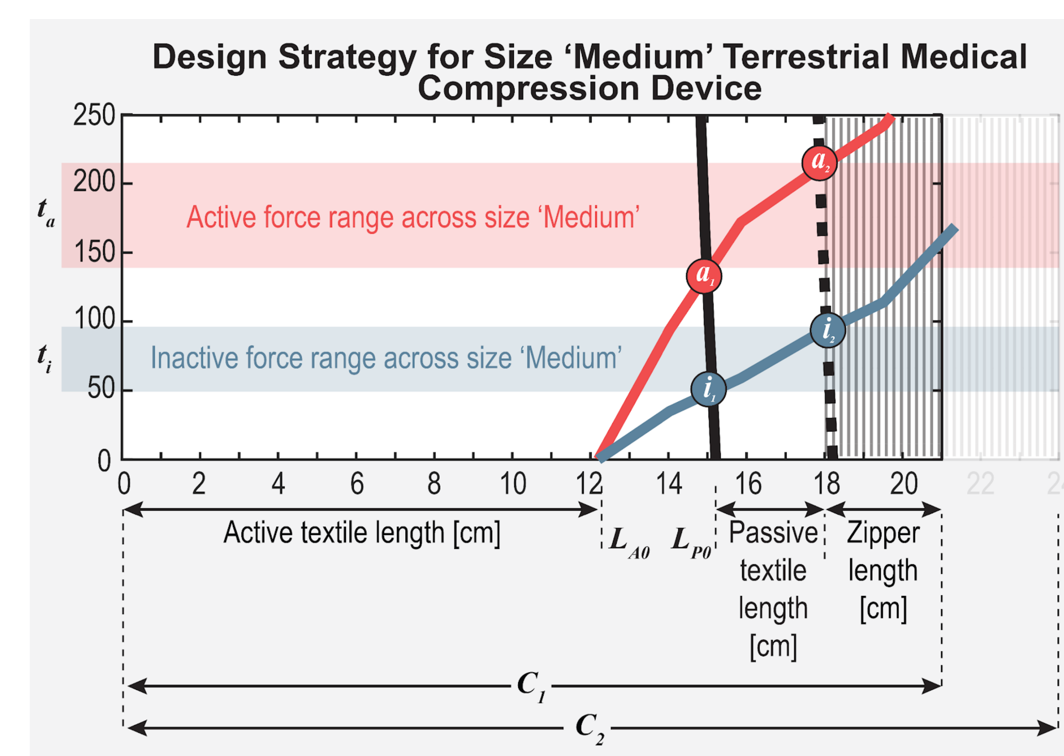

Figure 4. The design strategy for an active material compression stocking is (1) to produce an increase in stocking unit tension (t) from inactive (i) to active (a) states using a heating pad and (2) to minimize the inactive and active force ranges across the size category.

CONCLUSIONS

The design methods presented are being implemented to manufacture an experimental medical compression device using active materials. The device performance will be evaluated with on-body force and temperature sensing methods in an IRB-approved study in the spring of 2021. Future work with include a clinical trial to evaluate device usability in collaboration with the University of Minnesota Medical School.

REFERENCES

[1] L. Macintyre, "Designing pressure garments capable of exerting specific pressures on limbs," Burns, vol. 33, no. 5, pp. 579–586, 2007

[2] Granberry et al., 'Kinetically Tunable, Active Auxetic, and Variable Recruitment Active Textiles from Hierarchical Assemblies,' Advanced Materials Technologies, 2021.

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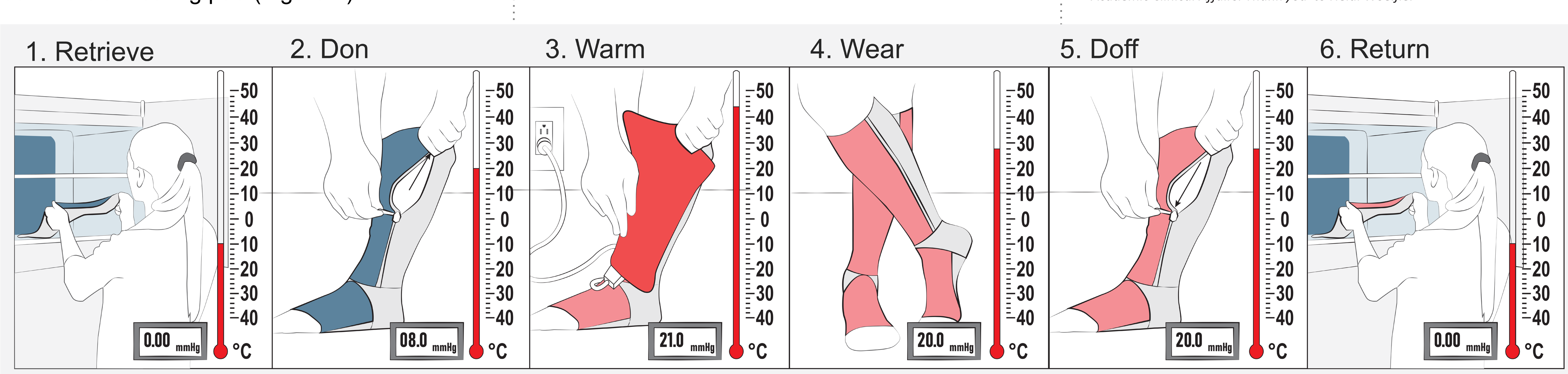

Figure 2. Medical compression device operation. The device is retrieved from a freezer (1) and is donned in a low compression state (2). A commercial heating pad is applied to the active material panel of the compression garment to activate the material and induce compression (3). Once activated the heating pad is removed and as the device cools to match the body surface temperature it will remain in the higher compression state (4). The device is doffed with zippers (5), then returned to the freezer to inactivate the active material panel back to its relaxed state (6).

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