PI: Prof. Dava J. Newman

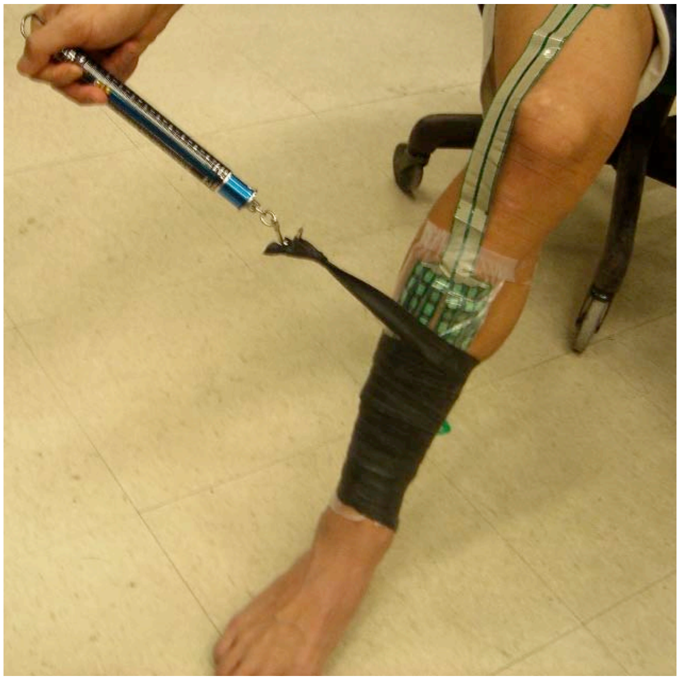


Figure 1. Elastic binding MCP concept and donning process. A spring scale is used to control the wrapping tension so that a uniform pressure is achieved over the entire leg surface. Tekscan™ sensors are placed between the leg and the prototype to measure the mechanical counterpressure distribution generated by the prototype.

Figure 2. Subject demonstrating deep knee squat to a knee flexion angle of approximately 150º, significantly higher than the ~80º achieved in previous MCP leg garments [1].

References:
[1] Annis, J.F. and Webb, P. development of a Space Activity Suit. NASA Contractor Report CR1892 (1971).

Design and Construction of a Mechanical Counter Pressure Elastic Binding Prototype

Two key limitations of previous mechanical counter pressure (MCP) leg garments have been donning/doffing difficulty and lack of joint mobility [1]. To overcome these limitations we investigated a novel MCP concept consisting of thin 1” elastic bands wrapped around the limbs in a similar fashion to medical bindings, or an ace bandage. The bands create MCP through elastic circumferential stress, thus, minimizing longitudinal stresses and maximizing mobility at the knee joint. The force with which the binding is stretched is varied as it is wrapped around the limb to achieve a uniform pressure distribution along the entire leg. Friction permits different sections of the binding to be stretched at different rates in order to create a uniform pressure distribution.

Several materials were investigated in order to find bindings with suitable elastic modulus and yield strain. Eventually, standard rubber inner tubes for bicycle wheels slit circumferentially to form a flat rectangular binding were deemed most practically suitable.

In donning the prototype, the user’s leg circumference is first measured at 0.5” intervals between the ankle and upper thigh. The circumferential tension necessary to produce the target pressure at each limb circumference is then calculated. The binding is attached to a spring scale and stretched to the appropriate tension as it is wrapped onto the leg (Figure 1). Friction between the comfort layer and binding allows different sections of the binding to be stretched to different tensions, allowing a theoretically uniform MCP to be generated over limb regions with different circumference.

The elastic bindings concept has proven to be extremely easy to don (less than 5 min per leg) and provides almost no hindrance to subject mobility as demonstrated by full leg flexion (Figure 2).

Testing: Elastic Bindings MCP Prototype

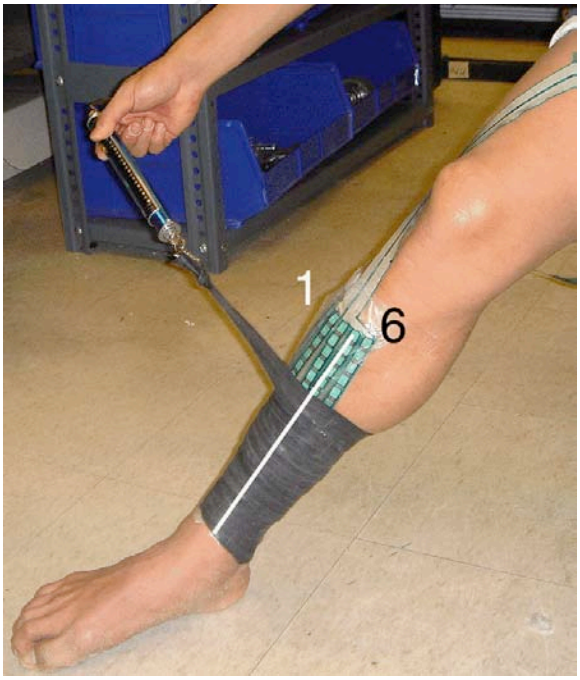
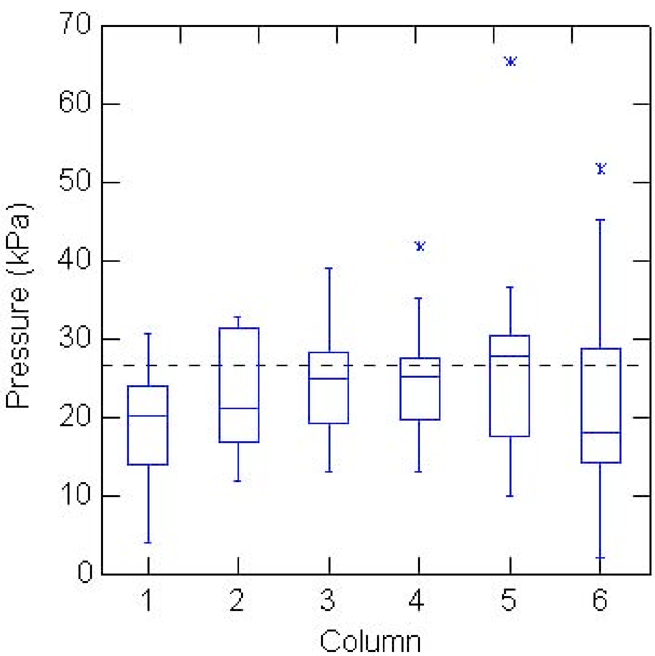


Figure 1. Tekscan sensor array placed on the anterior of the calf to measure the pressure generated by the elastic bands prototype. Sensor columns 1-6 are defined as shown, with column 5 running along the tibia. Each column has 16 individual pressure sensors ("sensels"), with the array having a total of 96 sensels.

The pressure generated by MCP garments must be as uniform across the body surface as possible to prevent adverse physiological consequences such as edema and pressure sores. We therefore measured the pressure distribution produced by the elastic bindings prototype on the calf using a Tekscan 9801 resistive pressure sensor array (Tekscan Inc., South Boston, MA) as shown in Figure 1. Measurements were taken at a range of knee flexion angles between 0°–90° at ambient conditions with a target mechanical counter pressure of 26.7 kPa (200 mmHg, 3.76 psi).

Data for the pressure produced on the calf at one flexion angle (30° – the leg's natural or "neutral" position) are presented herein, noting that results at other angles were not significantly different. At this angle, the average MCP on the calf in ambient conditions was 23.3±10.0 kPa at the anterior (Figure 2, left) and 22.5±7.5kPa at the posterior (Figure 2, right). The friction between the binding and slip layer over the skin allows the tension to be varied along the length of the binding, allowing a single binding to provide uniform row– and column–mean pressure on leg cross sections with different radii. Furthermore, although the results show a non-uniform pressure distribution between columns due to the tension in the bindings being adjusted only once per revolution (i.e., each time the binding was wrapped around 360º). Preliminary experiments suggest that the uniformity is considerably improved by adjusting the tension twice or even thrice per revolution.



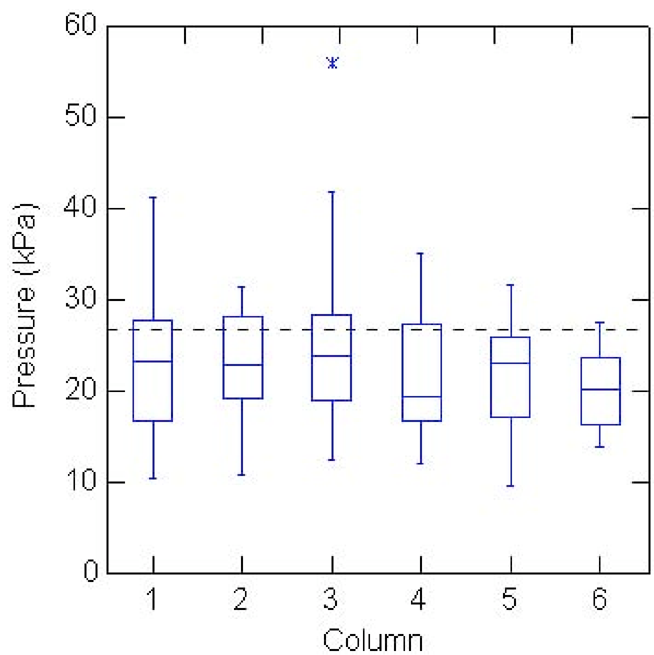


Figure 2. Mechanical counterpressure generated at the calf anterior (left) and posterior (right) by the elastic bindings prototype at 30° knee flexion angle. Each box plot shows the interquartile ranges and median pressures for the 16 sensors in the given sensor column. The 26.7 kPa target pressure is shown as a dotted line.