# COMPRESSION ENGINEERING OF SPORTS GARMENTS USING ATHLETES' ANTHROPOMETRIC DATA/3D SCANNING TECHNOLOGIES

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This research aims to develop sport compression garments (SCGs) for athletes and with the required compression. Graduated compression thigh-high socks were designed for the Alva-40 mannequin, and compression was measured using picopress instrument. The anthropometry of the mannequin and six male scans were analysed using 3D scanning size stream software. The compression results were modelled for six scans through fabric stress to strain (found through tensile testing) on the body using its dimensions and compared to mannequins with scans of similar dimensions at the ankle. Results found dimension variation randomly at different points for scans, leading to compression that was not progressive for modelled results. It concludes that wearing compression garments designed for one body has varying compression on other bodies.

**KEYWORDS:** Knitting, body dimensions, graduated compression, Picopress.

**INTRODUCTION:** SCGs are tight-fitting clothes with negative ease that athletes wear for their perceived advantages during and post-exercise activity. SCGs are believed to reduce muscle soreness, optimise blood flow, promote muscle oxygenation, decrease blood lactate, and minimise injury possibilities when worn correctly (Ashdown, 2011; Atkins et al., 2020; Born et al., 2013; Duffield & Portus, 2007; Fu et al., 2013; MacRae BA, Cotter JD, 2011; Sang et al., 2015), potentially enhancing both endurance and performance levels during exercise. Stretchable knitted structures provide the required extension, and elastomeric fibres offer recovery. In sports, human bodies are exposed to stress, and inappropriate motion or posture can result in injuries or subpar performances. In addition to providing the appropriate compression for various body profiles, the garment mustn't restrict movement (Science, 2019). With SCG fit, the size of a garment is proportional to the wearer's body measurements in relation to the required amount of compression. Consequently, commercial garments may not always provide the required amount of compression and may not always be a good fit (Ashdown, 1998; Gupta et al., 2006).
Utilising state-of-the-art imaging technology, 3D body scanning captures comprehensive information about the human body, including its measurements and shape (Gill, 2015). By combining 3D body scanning with textile garment production, performance-oriented, individually tailored apparel can be created (Gorea & Baytar, 2020).
The pneumatic pressure measurement device PicoPress measures the objective pressure applied on body by SCGs. The compression can be determined indirectly from compression material properties or computed using Laplace's Law or its derivatives (Lee et al., 2021).
Athlete anthropometrics, 3D scans and compression engineering still lack a thorough description of applied compression in accordance with the body dimensions, which is a critical gap. This study aims to develop compression garments for athletes with required graduated pressure by integrating knowledge from scan technologies, material properties, and modelled results. By integrating all this, it will also highlight the measurement points having varying dimensions and compression to make the necessary adjustment at the knitting design stage to achieve the required compression.

**METHODS:** SCGs were produced using a small-diameter of 360N, 4.75” diameter Merz circular knitting machine for the male Alva-40 mannequin (Alvanon). The mannequin was scanned using a Size Stream 3D body scanner. Six scans from CAESAR data with similar dimensions at the ankle were selected. Their details dimensions were examined through size stream software to compare the compression results with the mannequin. The scanned form of the mannequin is shown in Figure 2.

The yarns used to knit the compression garments were nylon as the main yarn (Blue) and elastomeric double-covered (DCV) with nylon as inlay yarn (Green), as shown in Figure 1. Experimental compression response was measured using a Picopress measuring device at six locations of both legs from ankle to thigh for the mannequin only, and made it to be graduated (Decreases from ankle towards thigh), as shown in Figure 1 (e), named as ankle, mid-calf, calf, under-knee, mid-thigh, and thigh. All these circumferences were measured at same height for the mannequin and six scans from the ankle, but the actual measurement, e.g., mid-thigh, located at slightly different heights for different scan bodies. The compression response of compression garments was also modelled for six scan bodies by mechanical characterisation using stress-strain and fabric properties, as reported previously (Teyeme et al., 2021) and comparison of actual mannequin and modelled results of six scans were made.

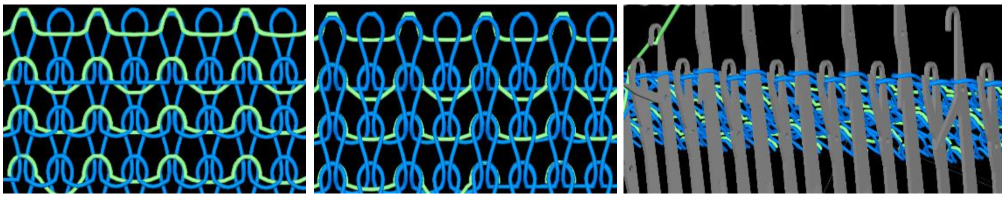

***Figure 1- Knitting structure and needle notation***

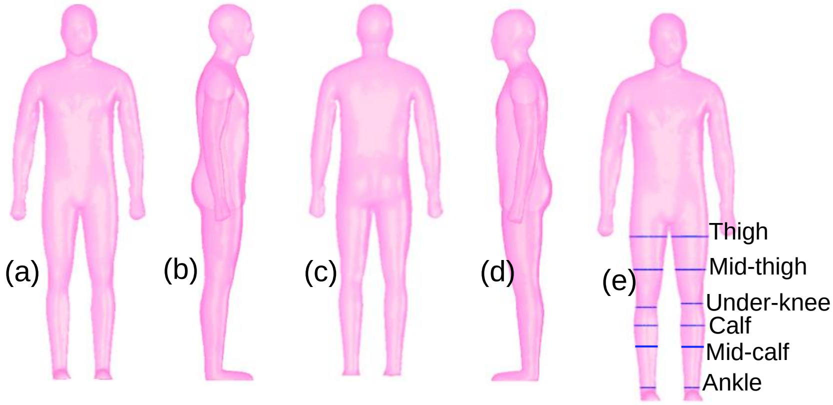


***Figure 2 Male Alva-40 scanned through Size stream***

**RESULTS:** The results of experimentally measured compression and its graduated percentage are shown in Figure 3. The surface of this mannequin form is hard and not reflect the actual human body compression, exerted by the garment when worn on soft tissue. It shows that the highest compression was at lower part of the leg at ankle and kept decreasing towards the thigh. It also shows that the garment compression is uniformly graduated (Brophy-Williams et al., 2015), and it will help to move the blood upwards.

*Table 1* represents the variation in the circumference of the Male Alva-40 form and six scanned bodies. All seven scans have same height (180 cm) and similar ankle circumference. Variations in circumferences found to increase as moved from ankle to thigh and were highest at the thigh. Interestingly, it could be observed that Scan 6 and Scan 5 had the largest circumference at the calf, whereas at the thigh scan 3 found to have the largest circumference and scan 6 had a circumference at fourth. It shows that dimension variations between different bodies are complex, and wearing a standard garment may result in different compressions on the bodies at various points (Song & Ashdown, 2015).

Table *1* shows the circumference from size stream and compression results modelled using these body dimensions and fabric mechanical properties. It shows that the compression garment, which designed for the Male Alva-40, has graduated compression on it, but its compression results would be different on one or more points on other bodies that have the same dimension at the ankle but different at other points. Two or more bodies can have the same dimension at one or more points but a different dimension at other points, resulting in the worn fabric having a different compression at varying dimension points. Interestingly, the compression results were found no longer to be graduated and may not help to increase the blood flow in the body by compressing the legs, but instead, applying more compression on the upper body parts of the legs will cause a block. Scan 3, which was found to have more circumference at the thigh, was found to have more compression, whereas Scan 6 compression was highest at the calf because of its highest circumference. It also concludes that if dimensions are larger than the assumed standard, compression will increase and vice versa. It highlights the need for custom-made scan-to-knit compression garments for athletes, as otherwise, the effectiveness of these garments will be limited, and they will no longer have positive effects on the performance of athletes (Brown et al., 2022).

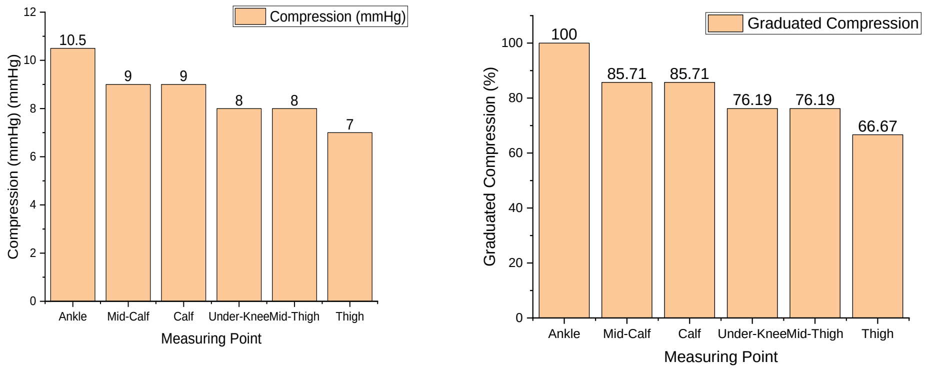


***Figure 3 Experimental compression measured at six locations and their graduated (%)***

***Table 1 Circumference and compression at different position of seven scan***

| Measuring Point | Ankle | | Mid-Calf | | Calf | | Under-Knee | | Mid-Thigh | | Thigh | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | mmHg | cm | mmHg | cm | mmHg | cm | mmHg | cm | mmHg | cm | mmHg |
| Male Alva-40 | 23.7 | 10.5 | 29.7 | 9.04 | 36.7 | 8.97 | 35.0 | 7.85 | 43.7 | 7.52 | 55.4 | 6.90 |
| Scan 1 | 23.3 | 9.60 | 29. 8 | 9.19 | 38. 6 | 10.4 | 37.4 | 9.01 | 46.5 | 8.62 | 53.7 | 6.03 |
| Scan 2 | 22.6 | 8.22 | 28.6 | 7.77 | 38.4 | 10.4 | 35.6 | 8.11 | 44.9 | 7.98 | 55.2 | 6.80 |
| Scan 3 | 22.4 | 7.86 | 31.0 | 10.6 | 40.1 | 11.7 | 41.0 | 10.74 | 52.5 | 10.79 | 64.5 | 10.55 |
| Scan 4 | 22.5 | 7.99 | 30.8 | 10.4 | 37.7 | 9.75 | 38.0 | 9.31 | 45.8 | 8.36 | 60.8 | 9.27 |
| Scan 5 | 22.9 | 8.74 | 32 | 11.9 | 41.4 | 12.9 | 40.1 | 10.31 | 49. 6 | 9.76 | 62.3 | 9.80 |
| Scan 6 | 22.7 | 8.41 | 32.9 | 13.1 | 43.1 | 14.4 | 37.9 | 9.23 | 44.7 | 7.94 | 59.7 | 8.83 |

**Discussion:** The current study results indicate dimensions and compression variation for a garment when it is supposed to be worn on different bodies. Compression and body dimensions correlate; if one increases, the other increases and vice versa. Interestingly, compression/dimensions were found to be higher at one point, but it was found lower at another point when compared between different scans, highlighting the challenge of using one garment for multiple bodies as reported for body dimensions (Brubacher, 2020)This study aims to integrate knitting, scanning, and modelling using fabric properties to develop garments with the required compression. Results highlight that the body dimension with varying compression requires necessary adjustments at the knitting stage to achieve the required compression. The results also highlight the importance of custom-fit compression garments, which can provide the required fit/compression. However, it will increase the cost of custom-fit production, and scanner availability will also be challenging.

**CONCLUSION:** This study highlights how the required compression in sports garments can be engineered more efficiently using 3D body scanning and fabric properties. 3D body scanning helps to have detailed measurements of the body. Using them in modelling and fabric properties can help highlight the garment's varying compression points for an athlete, which can create discomfort—making some necessary adjustments at the knitting design stage for the garment with required compression produced in fewer trials. It can be concluded that scan-to-knit garments provide a step towards a better fit and the required compression to the complex variation in different bodies of the same sizes.

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