2023 Proceedings Baltimore, Maryland

Comparison of two pressure sensors used for evaluating performance of compression apparel

Harman Ugra, Camren Monteverdi, Ryan Polino, Jacob Bishop, Jennifer Buckley and Adriana Gorea
University of Delaware

Keywords: pressure sensor, compression apparel, design

Background. Compression apparel is used by recreational and professional athletes during and after exercise, to enhance athletic performance and accelerate recovery following strenuous exercise (Textiles Intelligence Limited, 2019). These highly elastic next-to-skin worn garments achieve compression because of the force applied by the stretched fabric to a body area surface, therefore better represented as pressure (Tyler, 2015). The interface pressure on the body is designed using elastane yarns in weft-knitted fabrics along with a tight fit of the garments (Xiong & Tao, 2018). Repeated laundering and wear negatively affect the elastic fabric properties, leading to a loss of pressure performance for compression apparel (Easter & Ankenman, 2006).

The assessment of in-vivo interface pressure for compression garments is common practice in the medical field (Goldman, 2020). The most tested transducer pressure systems in studies regarding hosiery and athletic compression garments are the Kikuhime® (Meditrade, Soro, Denmark), Picopress® (Microlab, Padua, Italy) and the MST MKV® (Swisslastic, Gallen, Switzerland) (Flaud et al., 2010). The piezoresistive force sensors, offering electrical resistance that decreases as pressure on the sensor probe increases, are less commonly used because they are more expensive, but they have a lower profile and can be used with customizable systems. FlexiForce™ sensors (Tekscan, Boston, United States) and Texsens®-g (Novel, Munich, Germany) (Brophy et al., 2014). No studies have been found to compare the accuracy and reliability of these two piezo resistive sensors.

Conversations between the authors of this study and a major athletic apparel manufacturer in the United States highlighted the need for a wearable pressure sensing system that could help compression apparel designers visualize and evaluate the interface pressure for garments, such as compression arm sleeves. Several required sensor metrics have been already established by previous research. Such sensors should be thin (< 2 mm) and flexible and have a direct connection to a graphic interface (Jariyapunya & Musilová, 2019). They should sense pressure applied in the range of 0- 40 mmHg, and the sensing elements should be able to be located along prominent muscle groups (triceps, biceps, etc.) (Weakley et al., 2022). Performance benchmarking metrics for repeatability of sensor pressure measurements set the error of accuracy at ±2.5% within tested range (Drewniak et al., 2007).

Therefore, the purpose of this research was to investigate which commercial piezoresistive pressure sensor could be used by compression apparel designers into a customizable wearable solution to visualize and assess the performance of their designs, aiming to improve existing products by minimizing compression loss over time.

Method Based on the sensor performance benchmarking listed above, the two commercial pressure sensors found feasible for this study were Tekscan FlexiForce™ A201 and Novel Electronics Texsens®-g. FlexiForce™ A201 is a thin and flexible piezoresistive force sensor that is available in a variety of lengths, has a pressure range of 0- 510mmHg, linearity (error) <3% of full scale, repeatability <2.5%, sensor probe thickness of 0.203mm, and 9.53mm in diameter, but not compatible with Bluetooth (Tekscan, 2023). The Texsens®-g utilizes one fully calibrated, capacitive sensor which is connected to small and lightweight loadpad® electronics. Mobile data acquisition, real-time transmission via

Bluetooth, and data evaluation is captured with the loadpad® app for intelligent mobile devices. This sensor system measures pressure over time (continuous) within a range of 7.5-75 mmHg, has linearity (error)<3% of full scale, sensor probe thickness of 1mm, and 10mm in sensor diameter (Novel, 2023).

Both sensor types were first tested for accuracy on a flat tabletop surface, using ten trials of four disks of known masses placed on top of each sensor type. Rubber and acrylic disks were used to ensure equal distribution of mass within each object. The disks were placed on top of each sensor along with a 3D printed force concentrator object, designed with 10mm top diameter and 6mm bottom diameter. A second test for assessing sensors' accuracy over a curved surface was completed, to observe changes in pressure over anatomical type of shapes (arm diameter). Two PVC cylindrical pipes with 0.762m and 0.102m radius were used, along with a setup including the mass attached to a flexible belt (width= 0.023m), an Arduino Uno, Breadboard and a monitor to display the values of calculated pressure (P)= Tension/Radius *(width of belt).

The final in-vivo test for the two pressure sensors used two full length commercial medical compression sleeves fit to a volunteering participant to have: (1) low compression (15-20 mmHg), and (2) high compression (20-30 mmHg). To stabilize the extended right arm, a foam pad was placed at the armpit of the participant. The sensors were placed on five marked locations on the arm (bicep, forearm, upper triceps, center triceps and lower bicep). Sensor data was recorded through measured arm movements, such as: (1) arm straight down at side, and (2) elbow bent at 90 degrees.

Results and Discussion The tabletop accuracy test results showed that Texsens®-g closely matched the expected pressure, while FlexiForce™ A201 did not perform as well, with high errors at pressures >45 mmHg. The curvature test results showed that an increase in pressure was detected by both sensors, with increased weight over constant curvature as well as increase in curvature with constant weight. The field test for the low compression sleeve showed the Texsens®-g measuring within the targeted 15-20mmHg range at the bicep and upper triceps levels, but slightly out of this range for the other three locations. By contrast, FlexiForce™ A201 measured highly outside the targeted range for all locations except the forearm. The forearm and center triceps are the only locations where FlexiForce™ A201 performed better than Texsens®-g. For the high compression sleeve, Texsens®-g measured within the 20-30mmHg target range for bicep and center triceps, but slightly outside the range for the other three locations, while FlexiForce™ A201 measured outside the range for all locations except lower biceps. Overall, considering all the targeted performance metrics for pressure sensors that could be integrated into a wearable system attachable to a compressive garment, the Texsens®-g sensors outperformed and passed the test for accuracy (error of accuracy on sensor ±2.5% of tested range) and precision (repeatability of measurements with <5% variation), while FlexiForce™ A201 sensors failed these two requirements.

Significance. The results of this study highlight the importance of pressure sensor evaluation before selecting a specific one to be used for compression apparel performance monitoring. The accurate reporting of interface pressure can enhance interpretation of research findings and help substantiate manufacturers' claims of compression. Further studies should be conducted by using the same two sensors to evaluate compression in different areas of the body

References

Brophy-Williams, N., Driller, M. W., Halson, S. L., Fell, J. W., & Shing, C. M. (2014). Evaluating the Kikuhime pressure monitor for use with sports compression clothing. Sports Engineering, 17, 55-60.

Brubacher, K., Tyler, D., Apeagyei, P., Venkatraman, P., & Brownridge, A. M. (2023). Evaluation of the accuracy and practicability of predicting compression garment pressure using virtual fit technology. Clothing and Textiles Research Journal, 41(2), 107-124.

Drewniak, E. I., Crisco, J. J., Spenciner, D. B., & Fleming, B. C. (2007). Accuracy of circular contact area measurements with thin-film pressure sensors. Journal of biomechanics, 40(11), 2569-2572.

Easter, E. P., & Ankenman, B. E. (2006). Evaluations of the care and performance of comfort stretch knit fabrics. AATCC review, 6(11), 28.

Flaud P, Bassez S, Counord JL (2010) Comparative in vitro study of three interface pressure sensors used to evaluate medical compression hosiery. Dermatology Surgery, 36,1930–1940.

Goldman, R. J. (2020). Implementing a Wearable Sensor for Lymphedema Garments: A Prospective Study of Training Effectiveness. Wound Management & Prevention, 66(1), 39- 48.

Jariyapunya, N., & Musilová, B. (2019). Predictive modelling of compression garments for elastic fabric and the effects of pressure sensor thickness. The Journal of The Textile Institute, 110(8), 1132-1140.

MacRae, B. A., Cotter, J. D., & Laing, R. M. (2011). Compression garments and exercise: garment considerations, physiology and performance. Sports medicine, 41, 815-843.

Novel (2023). Texsens®: mobile load measurement in the textile and garment industry. Retrieved from https://www.novel.de/products/texsens/

Tekscan (2023). FlexiForce A201 Sensor. Retrieved from https://www.tekscan.com/productssolutions/force-sensors/a201

Textiles Intelligence Limited. (2019, October). Compression wear and shapewear: Supporting health and fitness. Performance Apparel Markets, 66, 41–95.

Tyler, D. (2015). Application of pressure sensors in monitoring pressure. In S. Hayes & P. Venkatraman (Eds.), Materials and technology for sportswear and performance apparel (pp. 289–309). CRC Press.

Weakley, J., Broatch, J., O'Riordan, S., Morrison, M., Maniar, N., & Halson, S. L. (2022). Putting the squeeze on compression garments: current evidence and recommendations for future research: a systematic scoping review. Sports Medicine, 52(5), 1141-1160.

Xiong, Y., & Tao, X. (2018). Compression garments for medical therapy and sports. Polymers, 10(6), 663.