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Preliminary Development of a Wearable Device for Dynamic Pressure Measurement in Garments

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Abstract

During activity, the body's limbs experience significant anthropometrical changes as muscles and tendons exert force for motion and stability. This dynamic motion is of interest to sports compression garment manufacturers who seek to enhance sports performance through gradient compression garment design. Existing devices for measuring garment pressure are generally not well suited to dynamic pressure measurement during sports activities due to limited portability, memory, communication and power capacity. A wearable wireless monitoring device was constructed, which included six 18mm diameter low profile pressure sensors that were placed on the body at various positions, e.g. on the calf, thigh, and buttocks regions, to sense garment pressure in the range of 5 – 50mmHg. The accuracy and precision of the wearable dynamic pressure monitoring device was explored using a series of step changes in pressure effected through the placement of a series of known masses. Similar tests were also conducted with the Kikuhime ™ and PicoPress ™ for comparison. Further tests to explore the performance of the wearable dynamic pressure monitoring device to monitor changes in pressure between a subject and garment during various activities were also performed. The performance of the wearable dynamic pressure monitoring device is discussed in terms of portability, dynamic response, accuracy, precision, resolution and general utility. It was generally found to be acceptable for further field studies. Wireless dynamic pressure monitoring devices represent a tool that could be utilised to help further understand and characterise dynamic compression in various sports activities. Such a device would enable functional testing and provide valuable information on dynamic compression values and the physiological efficacy of gradient compression garment design.

Keywords: compression garment; dynamic pressure; wireless;

1. Introduction

During activity, the body's limbs experience significant anthropometrical changes as muscles and tendons exert force for motion and stability. This dynamic motion is of interest to sports compression garment manufacturers who

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seek to enhance sports performance through gradient compression garment design. These designs are typically derived from the analysis of human morphology, anthropometry and static measures of compression.

Existing devices for measuring garment pressure, such as the Kikuhime ™ pressure monitor (TT MediTrade, Sorø, Denmark) and PicoPress ™ pressure monitor (Microlab Ellettronica Sas, Italy) are predominantly utilised within the medical field, and are generally designed for static measurement in the range of 5 – 50mmHg [1-3]. The functional application of these devices is not well suited to dynamic pressure measurement. They have limited portability and capacity during specific sports conditions [3-5].

2. Methods

A CSIRO wearable monitoring system [6] was configured to sense garment pressure at various locations around the body in the range of 5 – 50mmHg (0.667 – 6.67 kPa). The system (Figure 1a) included:

1. 6 input wearable 915MHz Transmitter (8 bit sampling at 250Hz)
2. 6 low Pressure sensors with leads (on one plug)
3. Belt for supporting electronics and attaching to subjects
4. USB stick 915MHz Receiver
5. Software for logging data to a common file on a PC with Windows XP (or Vista) operating systems
6. 6 sets of masses for calibration (3x 100g, 3x 50g)
7. Standard USB A plug to USB Mini-B plug cable for recharging

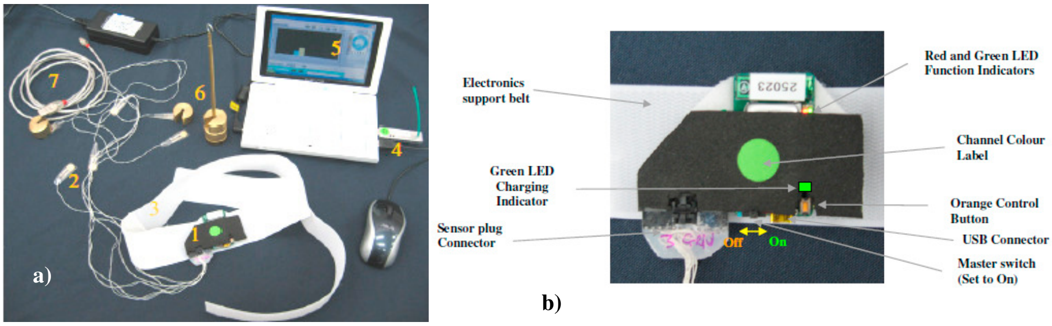

Fig. 1. a) Wearable pressure monitoring system, b) System transmitter features.

The wireless transmitter had a variety of interface features for operation see Figure 1b. These include a black master switch, an orange control button, a red and green LED indicator for identifying device calibration and signal transmission functions, a green LED to indicate charging, a USB connector (for recharging and firmware manipulation), a connector plug for sensors, and a colour label used to identify communication channels within 915MHz band. A corresponding receiver unit for that channel colour was used. A 230mAh battery provided a continuous operation life of in excess of 8 hours.

Low profile pressure sensors were formed by locating a Flexiforce 1 lb-f sensor between two 18mm diameter precision machined disks. The accuracy and precision of the wearable dynamic pressure monitoring device was characterised using a series of step changes in pressure applied via the placement of a series of known masses. Similar tests were also conducted with the Kikuhime ™ and PicoPress ™ for comparison. The sensors were placed on a steel backing plate and aligned so that the mass could be placed on them in quick succession. The sensor values were logged to a computer via the wireless system. The computer logging was initiated and after 5 seconds a 100g mass was placed carefully on all of the 6 sensors. This was left for 10 seconds. Further sets of 100g mass were then added at 10 second intervals until a total of 300g was reached. The mass was then removed in a similar 100g step wise fashion in 10 second intervals until all mass was removed. The process was repeated using a set of 50g mass (to a maximum of 150g). Two replicates for each mass set were collected. Six sets of six sensors were characterised in this way. The average sensor reading over a 1 second interval, selected from the middle of each step, was used for calibration.

A set of six low profile sensors were selected from the sensor characterisation and calibration study to form a new set comprising sensors which were found to have good repeatability and a linear response in the range of 5 – 50mmHg. These were used to explore the performance of the wearable pressure monitoring device to monitor changes in pressure between a subject and garment during running. The six sensors were placed on the body at various positions, e.g. on the calf, thigh, and buttocks regions as shown in Figure 2. The sensors were individually coloured to enable easy identification. The subject was then fitted with a pair of compression tights (Skins ™ sports compression garment, size L chosen for the subject based on their BMI).

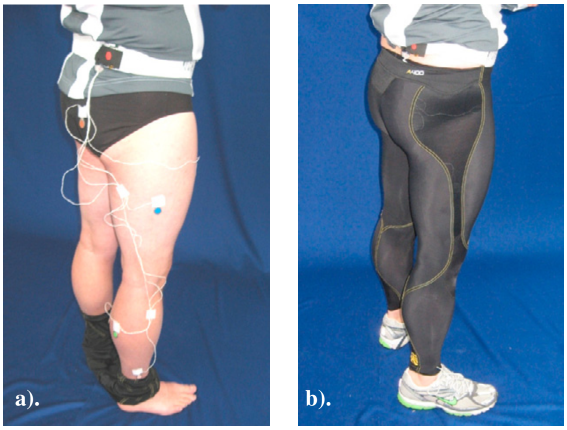

Fig. 2. Wearable dynamic pressure monitoring device on subject, a) No garment, b) Under garment.

3. Results

The characterisation of one of the sensors is shown in Figure 3a. The stepwise loading of the sensors is evident and the initial spike is indicative of the impact of the mass on the sensor. A calibration of sensor value with pressure was derived from this as shown in Figure 3b.

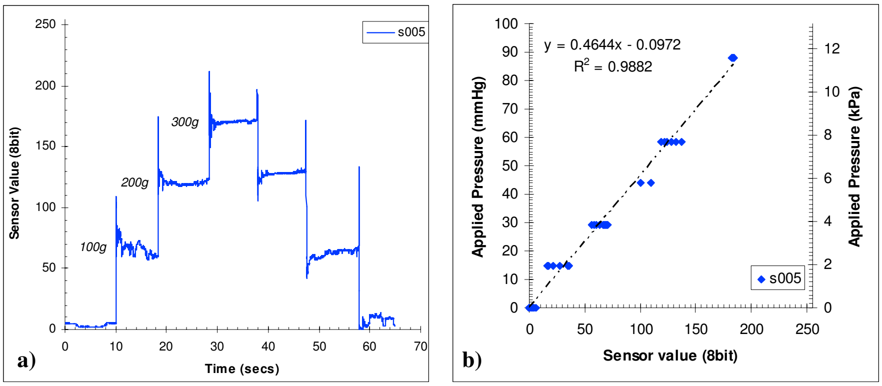

Fig. 3. Sensor characterization, a) Step test result, b) Calibration of sensor value and pressure.

Figure 4a shows the static measures for similar testing with the kikuhime ™ and picopress ™devices. In general, approximately 1 in 4 modified Flexiforce sensors were selected as having an acceptable performance. Whilst some sensors, like that shown in Figure 3, appeared to have a repeatable linear response, other sensors were less repeatable and had less predictable responses, see Figure 4b and 4c which were considered to be unacceptable relative to the performance of the Kikuhime ™ and PicoPress ™ devices (Figure 4a). The Kikuhime ™ and PicoPress ™ have a number of drawbacks beyond being constrained to static measures. Their accuracy and precision in terms of measuring garment pressure on complex shapes remains in question (mainly because of the use of a thick tube, the compressibility of air, uncertainty over the area of measurement, and potential for air leakage from the system).

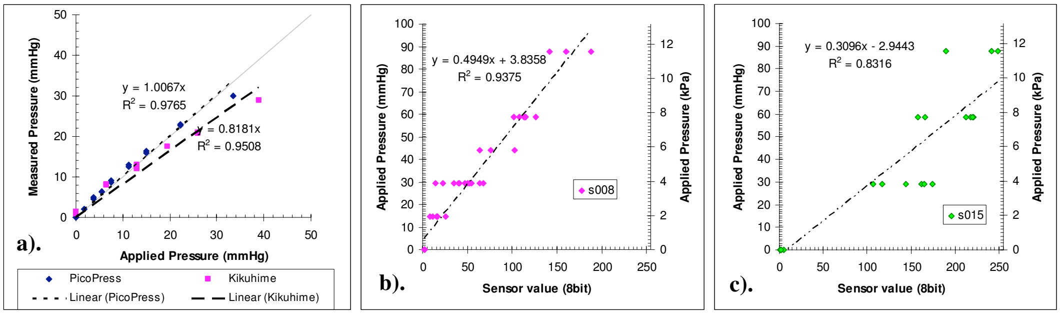

Fig. 4. Sensor calibration and characterization a) Kikuhime ™ and PicoPress ™, b) Modified Flexiforce sensor with unacceptable precision, and c) Modified Flexiforce sensor with poor linearity and precision.

The calibration equations for six low profile sensors found to have good repeatability and a linear response in the range of 5 – 50mmHg are shown in Table 1.

Table 1. Calibration of wearable pressure monitoring device sensors

Pressure(mmHg) = m x *SensorValue (8bit) + C*

	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
location	*Achilles*	*Med Calf*	*Lat Calf*	*Lat Thigh*	*Front Thigh*	*Gluteus*
m	0.2046	0.2278	0.178	0.2568	0.2516	0.2978
C	-1.7931	2.0275	-1.4383	-1.71	0.6797	-1.2895
R^2	0.9615	0.9593	0.9872	0.9942	0.9737	0.9753

The performance of these sensors was deemed acceptable whilst not necessarily as precise as the kikuhime ™ and Picopress ™devices, particularly at pressures below 5mmHg. These sensors were used to form a sensor set for the wearable pressure monitoring device to monitor changes in pressure between a subject and garment during running.

Figure 5 shows the pressure variations during running that were recorded with the wearable dynamic pressure monitoring device (approximately 6 steps). A regular pattern of signal variation consistent with cyclic muscle movement is evident. In general, it appears that the compression gradient the garment applied to the leg was maintained throughout the movement. Further work is required to understand the relationship of the complex peak garment pressure patterns to local muscle activity.

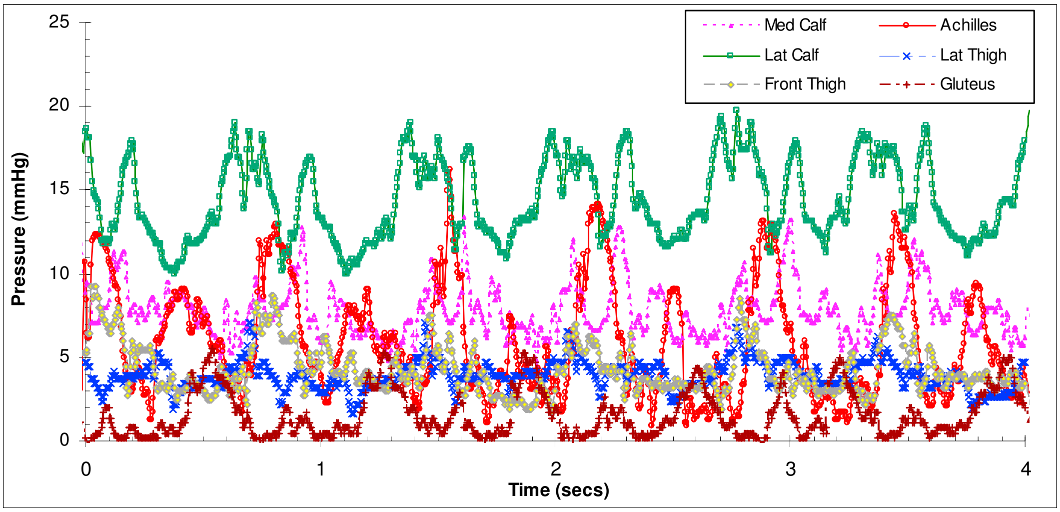

Fig. 5. Variation in garment pressure during running at various positions as measured with the wearable dynamic pressure monitoring device.

The average pressure and peak pressures detected with the wearable dynamic pressure monitoring device (WDPMD) were generally consistent with the garment pressure measured with a conventional static pressure instrument, see Figure 6.

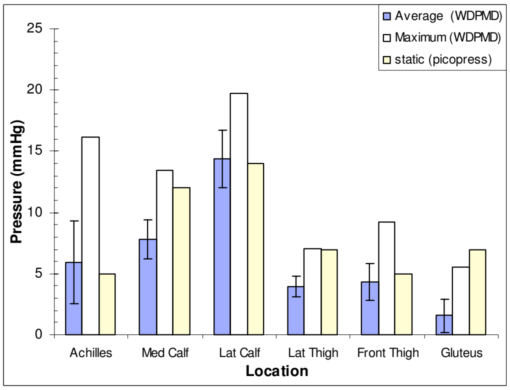

Fig. 6. Comparison of dynamic (running) and static garment pressure.

The wearable dynamic pressure monitoring device was very portable and had good general utility. The choice of sensor and the disk size was important for detecting low pressures (low mass) with reasonable precision at various locations on the body. The use of larger diameter sensors would improve precision (at the expense of resolution). The accuracy and precision varied significantly between individual sensors. Careful selection was required to prepare a device with acceptable performance. The calibration routine used here was developed to facilitate quick field tests (placement of a 200g mass) to check calibration drift during field trials. A more detailed calibration and characterisation test method is required to characterise the dynamic performance and optimise the electronic filters. Overall, the sensor resolution and dynamic response of the wearable pressure monitoring device was found to be acceptable for further field studies.

The physiological efficacy of gradient compression and its relationship to garment design is not generally well understood. A number of studies published to date have not addressed the need to collect dynamic compression data, which may be due to a lack of functional testing procedures and devices [4-5, 7-12]. It is current practice for sports compression research to adopt compression testing procedures from medical industry guidelines [13]. However, sports compression focuses on recovery and performance enhancement, whereas medical compression is more directed towards clinical application of patients with chronic venous insufficiency and lymphatic diseases. The garment design to achieve activity outcomes and physiological impact could require quite different garments for sport than those developed for medicine. Wireless dynamic pressure monitoring devices represent a tool that could be utilised to help further understand and characterise dynamic compression in various sport and rehabilitation activities.

Future sports compression garment research could utilise a portable dynamic compression device to enable functional testing and provide valuable information on dynamic compression variation with garment design. This may warrant the development of international standard procedures and possibly require the formation of an International Sports Compression Committee to develop guidelines to enhance evidence-based sports compression therapy in the sports compression industry.

4. Conclusion

Wireless dynamic pressure monitoring devices represent a tool that could be utilised to help further understand and characterise dynamic compression in various sports activities. The dynamic pressure monitoring device was found to measure garment pressure with reasonable precision and compared favorably with the Kikuhime ™ and PicoPress ™. The device was found to be suitable for monitoring changes in pressure between a subject and garment during various activities and had advantages in terms portability, memory, communication and power capacity. The device enables functional testing to provide valuable information on dynamic compression values to explore the physiological efficacy of gradient compression and garment design.

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