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New calibration method for I-scan sensors to enable the precise measurement of pressures delivered by 'pressure garments'

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ABSTRACT

Accurate measurement of the pressure delivered by medical compression products is highly desirable both in monitoring treatment and in developing new pressure inducing garments or products. There are several complications in measuring pressure at the garment/body interface and at present no ideal pressure measurement tool exists for this purpose. This paper summarises a thorough evaluation of the accuracy and reproducibility of measurements taken following both of Tekscan Inc.'s recommended calibration procedures for I-scan sensors; and presents an improved method for calibrating and using I-scan pressure sensors. The proposed calibration method enables accurate (±2.1 mmHg) measurement of pressures delivered by pressure garments to body parts with a circumference ≥30 cm. This method is too cumbersome for routine clinical use but is very useful, accurate and reproducible for product development or clinical evaluation purposes.

1. Measuring pressure at the garment/skin interface

A number of medical conditions are treated, controlled or prevented by applying pressure to the body via garments, hosiery or bandages; these include hypertrophic burn scars, varicose veins, leg ulcers and deep vein thrombosis. The pressure and pressure gradient delivered during each of these treatments determine treatment efficacy and the avoidance of complications, typically arising from excess pressure or incorrect pressure gradient. These treatments involve applying moderate pressures of between 6 and 50 mmHg, which are often at the lower end of the measurement range of commercial pressure sensors [1–3]. This often leads to measurement inaccuracy at low interface pressures [3–6]. In addition to this many pressure treatments are applied to body parts with low radii of curvature, a situation that brings about particular challenges for many sensors. For some sensor types, such as Talley, Oxford Pressure Monitor or Kikihume sensors, the sensor itself slightly increases the circumference due to its thickness and operating method while potentially significantly decreasing the local radius of curvature at the measurement point. According to the Laplace Law, such a reduction of curvature radius results in the pressure being raised [2,6–10].

The ideal sensor for recording low interface pressures would be thin, flexible and not distort the skin [1,11,12]. For these reasons the I-scan and Flexiforce sensors produced by Tekscan Inc. have been widely used in recent years for measuring the pressures delivered by medical compression products [3,5,13,14], eyelid pressures [15] and biomechanical interfaces [16,17] such as between amputation stumps and prosthesis. Some researchers have been satisfied by the sensor accuracy and ease of use [13,16], while others have questioned their accuracy under certain measurement conditions [3,5] and done work to optimise the use of the sensor and its calibration for their application [14,15,17]. A recent publication by Brimacombe et al. [17] advocates investigating the sensor's

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behaviour and optimal calibration method for each different application. This paper presents work conducted to optimise the calibration method for the measurement of pressures between 5 and 50 mmHg as applied by pressure garments to larger limbs and body parts of circumference ≥30 cm.

The new Pliance X sensors, based on capacitive sensing technologies are very promising for static pressure measurements, having been evaluated favourably and used by one research team for pressure garment measurements [12]. These researchers reported good results with this sensor, which appears to have similar positive attributes to the I-scan and flexiforce sensors while overcoming some of their documented limitations [12]; these researchers have called for others to investigate Pliance X sensors further.

At the time this study was undertaken the most promising sensors for measuring low interface pressures delivered by medical compression garments were those produced by Tekscan Inc. and these systems remain a lower cost option than the Pliance X system. Several research groups have found Tekscan sensors useful and reliable tools once the calibration has been optimised for their application. The calibration method described in this paper gave reliable and accurate interface pressure measurements delivered by pressure garments on large limbs as previously reported [14].

2. Introduction to I-scan sensors and their limitations

I-scan sensors are available in many shapes and forms, optimised for different applications. The sensor used in this study was the '9801' sensor with 6 columns of 16 sensing cells. I-scan sensors are temperature sensitive and therefore all calibrations and measurements should be conducted under similar temperatures. All the work described in this paper was conducted in a 'conditioned laboratory' that maintained a temperature of 20 ± 2 °C and 65 ± 2%RH. It was, however, noted in measurements reported in a previous paper [14] that the skin temperature of volunteers had no significant impact on pressure measurement accuracy. The measurements of these sensors are also susceptible to 'drift', with an increased value over time of the measured pressure. In order to minimise this effect, all measurements in this study were recorded at 30 ± 1 s after pressure application. Sensors were allowed to relax for 90 s between measurements thus avoiding residual readings.

'9801' sensors have a measurement range of 0–260 mmHg. However, the sensitivity of the sensors can be adjusted using the I-scan software to optimise the sensor output to a particular measurement range. In this study the software was adjusted to 'mid2' setting to give maximum measurement accuracy in the range from 2.5 to 50 mmHg. Further, since the sensors were ultimately to be used to measure the pressure delivered to cylinders and the human body on a variety of non-flat sites, 4 thin slits were cut between each pair of sensing cell columns; this reduced the incidence of sensing cells becoming loaded when the sensor was bent.

I-scan sensors use resistive inks sandwiched in cells between 2 layers of plastic film. Air can become trapped between the layers so before use the air must be manually squeezed out of the sensor. This was done before use by pressing hard on the surface of the sensor and drawing the fingers from the handle end to the tip of the sensor 3 times. The sensor must also be conditioned by applying the maximum expected load to the sensor for 30 s 3 times in a bladder tester or other device designed to apply pressure evenly across the whole sensor prior to use.

The application of pressure to these sensors causes the resistance of each sensing cell to change in inverse proportion to the force applied. The sensing cells on any sensor are not all identical. Therefore, before use, the manufacturer recommends equilibration by applying a uniform pressure to the sensor in their bladder tester. The software of the system then compensates for the variations between the individual sensing cells. In practice this procedure made little difference to the output of the sensors. A simple experiment was conducted by loading the sensors in the bladder tester according to manufacturer's instructions both before and after equilibration of sensors. Table 1 shows the coefficient of variation (%CV) of the 96 sensing cells of three un-equilibrated '9801' sensors and the same three '9801' sensors after they were equilibrated according to the manufacturer's recommended procedure at four different loads. The variation in sensing cell output after equilibration was lower than before equilibration but remains significant. Since there was some improvement in sensor feedback after equilibration all sensors were equilibrated throughout this study. However, the fact that high levels of variation still existed after equilibration is a limitation of the sensors. This variation in the reported pressure output of different sensing cells when consistent pressure was applied means that the output of individual sensing cells cannot be trusted and the mean pressure applied to/measured by all loaded cells should be quoted.

3. Evaluation of recommended I-scan calibration methods

Calibration should be conducted under conditions as similar as possible to those used in measurement. This includes selection of the materials that will be in contact with the sensors

Table 1 – Effect of equilibration on the variation of sensing cells under load.

Load in g	% CV un-equilibrated sensors				% CV of equilibrated sensors			
	1	2	3	Mean	1	2	3	Mean
200	27	25.6	28.9	27.2	26.3	25.6	25.1	25.7
400	23.6	23.6	22.2	23.1	20.3	19.2	19.4	19.6
600	19.1	17.6	17.1	17.9	15.5	16.5	15.6	15.9
800	16.3	17.4	16	16.6	15	13.6	13.4	14