CALIBRATION AND MONITORING OF PIEZORESISTIVE CONTACT STRESS SENSOR ARRAYS USING A TRAVELLING PRESSURE WAVE PROTOCOL

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INTRODUCTION

To improve the accuracy and efficiency of measuring the distributions of intra-articular contact stresses during dynamic loading of cadaveric joint specimens, a novel hardware and software regime has been developed for calibrating Tekscan sensors.

In many experiments measuring contact stress, especially those involving cadaveric joints with malreduced fractures or total joint replacement prostheses, high localized stresses lead to significant local changes in sensor responses during a given testing session. The ability to easily and frequently recalibrate sensors is therefore desirable.

METHODS

Figure 1. The calibration device with a sensor between the rollers.

To meet this challenge, a novel "wringer" device was built (Figure 1). Regulated air pressure applies a known force across a pair of elastomeric rollers. As the sensor is drawn between them, a traveling pressure wave is recorded (Figure 2A). Passage of the wave over each sensel is recorded as a time series signal. A finite element solution of the contact between parallel elastic cylinders provides a normalized distribution of pressure as a function of contact patch width. The spatial position of every sensel within the contact patch is known, allowing local pressures at every point in time to be based on the FE solution. A provisional calibration is derived using iterative power law curve fitting to the sensel-specific signal-pressure data arrays.

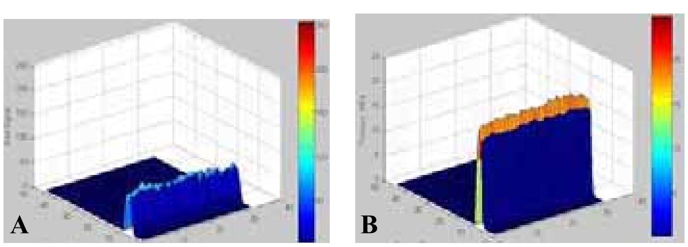

Figure 2. Traveling wave of raw (**A**) and pressure calibrated (**B**)

In these sensors, the area of the active pressure sensing elements constitute only about 10 percent of the total area over which the pressure is calculated. Calibration therefore depends on the distribution of load between sensing and non-sensing areas of the sensel and is strongly affected by the compliance of the surfaces between which the sensors are used.

After the provisional calibration, a sensor was inserted into a joint specially prepared so that all the load across it is carried by the sensor, and the calibration was "fine-tuned" at a series of known loads to the specific surface compliance properties of the joint's intra-articular environment. A *cartilage tuning factor* of 1.36 (the ratio of load applied to load recovered using the provisional calibration) was then used to adjust the provisional curves for each sensel. (Figure 3A). These final calibration curves were applied to eight other ankle loading experiments (Figure 3B).

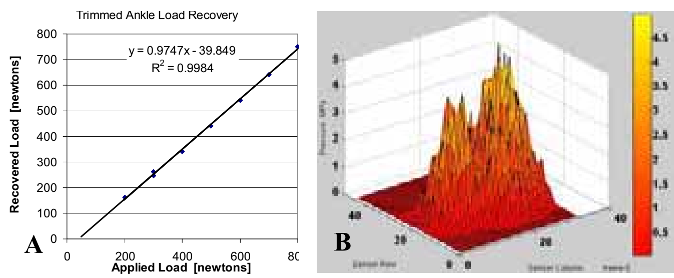

Figure 3. (**A**) Recovered load versus applied load is linear. (**B**) Pressure distribution in a cadaveric ankle loaded to 800N.

RESULTS AND DISCUSSION

The traveling wave technique serially calibrates the entire array of piezoresistive sensing elements over its full functional range while obviating the prohibitively high forces required for calibration using conventional whole-sensor-loading techniques.

At intervals during a typical experimental session, the sensor is removed from the joint and run through the device. Using the tuning factor already calculated, an updated calibration is calculated for each sensel. The sensor is then placed back in the joint and the experiment continues. If too much change (implicitly degradation) is seen to have occurred, the sensor is replaced. With minimal disruption of the protocol, the sensor's performance can be evaluated as often as desired during the course of an experiment. Data that might otherwise be lost to sensor artifacts can be saved by these on-the-fly recalibrations.

CONCLUSIONS

The manufacturer's calibration procedure, which restricts sensel loadings to the low end of the functional range and cannot provide sensel-by-sensel calibrations, may be problematic in many research environments. The new device and method effectively overcome these limitations.

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