Investigating the Force Sensitive Resistor as a Sensor to Measure Axial Puncture Forces

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INTRODUCTION

Virtual training simulators (VTS) for needle punctures reduce costs for theatre training and the risks to patients [1]. Realism of simulations can be increased by collecting *in vivo* force data, before programming the VTS. This requires force sensors to be accurate i.e. the extent to which measurements agree with the accepted values, and precise i.e. measured results are reproducible. However, sensors can be obtrusive and compliance with ethical regulations can limit their *in vivo* use [2].

Capacitance pads are small and have been used e.g. by Healey *et al* to measure *in vivo* arterial axial puncture forces. The sensor was placed onto the finger under the latex glove, were unobtrusive and did not affect the operator's feel during the procedure [3]. Alternatively, force sensitive resistors (FSR) [4] are small and can also be placed onto fingers. We present our data for axial needle forces obtained using FSR for the puncture of lumbar and prostate phantoms and test the FSR accuracy and precision. We demonstrate that force profiles collected from the FSR allow for identification of simulated tissue layers in the phantoms. We finish by comparing our axial force profiles for lamb liver puncture with ox liver puncture published by Healey *et al* who used the capacitance sensor.

MATERIALS AND METHODS

For *in vitro* use, the FSR (4mm, Interlink Electronics FSR™ 400) was sown onto the thumb of a Propeller glove and connected to an Arduino Uno board [5] using enamelled copper wires (fig. 1). An algorithm, published by Adafruit Industries [6], to convert analog voltage readings into newtons was programmed into the microcontroller. and calibrated using domestic quality 200g, 500g, 1kg and 2kg masses, with data sampled every 15ms (66.7Hz). Axial needle forces were measured for simulated lumbar puncture using a spinal needle on the EIT100 Lumbar Epidural Trainer [7] at Gwynedd Hospital, and a Bard needle gun [8] on a prostate phantom [9] at Yale Hospital Wrexham. Procedures were performed as consistently as possible, and repeated so as to identify non-axial movements.

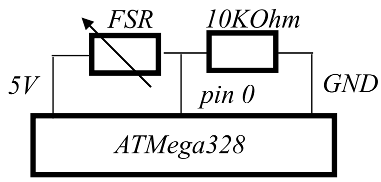

Fig. 1 Arduino and FSR voltage divider circuit.

RESULTS

Mass / g	Average Force / N	Standard Deviation	Accuracy / N
200	1.31	0.0349	-0.650
500	4.50	0.149	-0.400
1000	9.85	0.196	+0.0400
2000	19.2	0.313	-0.460

Table 1. Calibration data for the FSR sensor.

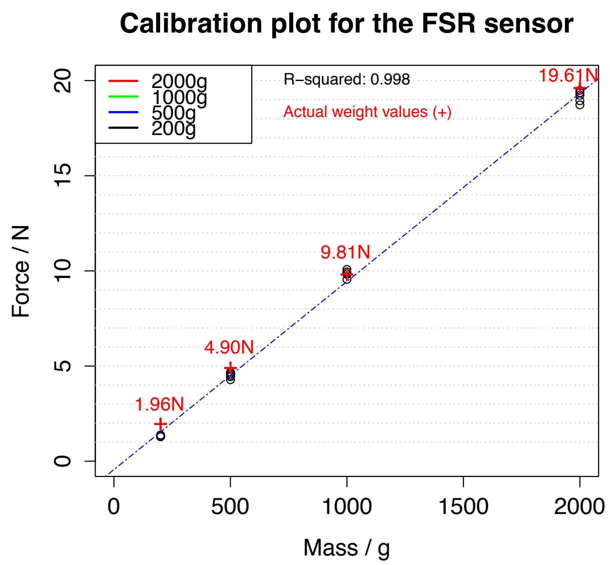

Fig. 2. Calibration plot using FSR. Actual values of the domestic weights are in red and noted with a '+' .

DISCUSSION

Figure 2 was created by selecting the first five samples over 1.25s (250ms rate) for each mass and calculating the mean (table 1). A strong linear correlation (R^2 0.998) is shown with the actual weight in red mostly falling within the recorded ranges of measured force. Standard deviation (table 1) is small, suggesting the sensor is precise. Accuracy measured as the difference between the mean values and the actual weight, in red, seem independent of the mass. We assume the drifting in force values over 15s (fig. 3) is caused by further compression of the FSR internal resistive polymer until its internal forces equals the load. Calculating the difference in means between the initial five and last five samples (mean drift values, fig. 3), shows more drifting under heavier loads i.e. reduced accuracy. Visual inspection of figure 3 also suggests reduced precision over time, more clearly seen for 200g and 1000g at 15s.

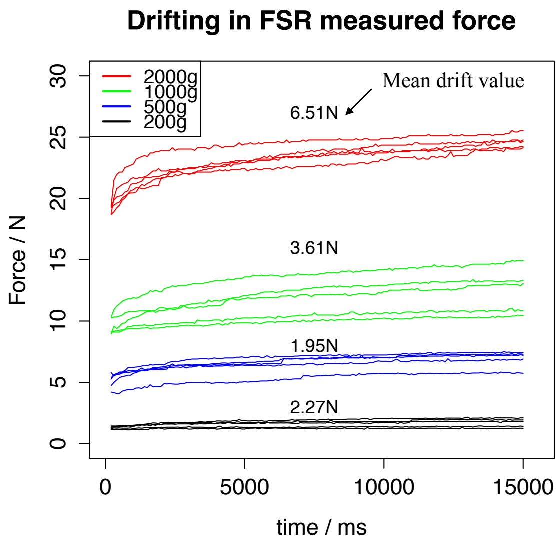

Fig 3. Drifting of values while domestic weights remain on the FSR pad. Sample rate: 100ms

Force profiles obtained for lumbar and prostate phantoms, using FSR, show identifiable tissue layers (fig. 4). However, force magnitudes will not be accurate due to the drifting mentioned earlier. The lower magnitudes in Fig 4 **A** are caused by non-symmetric force distribution over the FSR pad, but is rectified by correctly placing the sensor during the simulation.

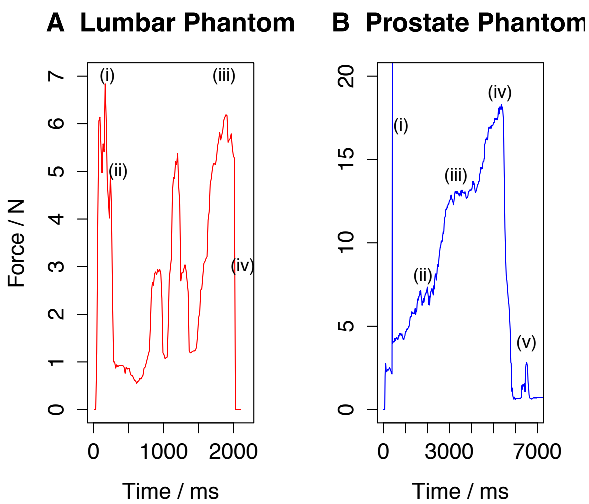

Fig 4. **A** (i) skin (ii) fat layer (iii) *ligamentum flavum* (iv) epidural space. **B** (i) + (ii) perineal membrane (iii) capsule (iv) prostate (v) firing of the needle.

Comparing the force profile of punctured ox liver [3], with our data for sheep liver using FSR, showed a similar profile with the characteristic rise in needle friction during puncture (fig. 5). Differences in friction forces associated with both needles are also observed in figure 5. Changes in the magnitudes of repeated measurements further illustrate the inaccuracy of FSR, though the profiles shapes are generally maintained.

CONCLUSION

We summarise that FSR has reduced accuracy and precision when used longer than a few seconds due to drifting in values. Unsymmetrical load distribution can also be a factor. Because FSR is facile at measuring force profiles during needle puncture, our future work will be to develop a biopsy guide using the FSR sensor, for monitoring needle force profiles in real time.

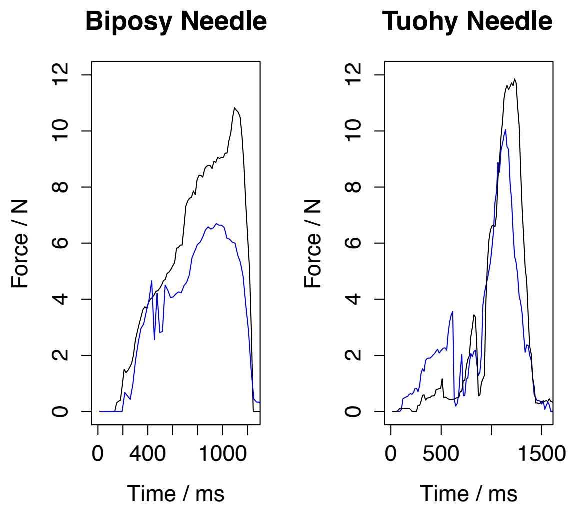

Fig. 5. Sheep liver puncture using a biopsy and Tuohy needle. Puncture was repeated with both needles.

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