

Quantifying Spinal Cord Swelling using Fiber Optic Pressure Sensors

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I. INTRODUCTION

Spinal cord swelling is an indication of severe spinal cord injury (SCI) [1-2]. Swelling may have negative effects on neurological outcome by inhibiting the flow of cerebrospinal fluid (CSF) and causing a decrease in blood flow within the spinal cord [3]. Swelling may also contribute to spreading of the spinal cord lesion causing additional damage above and below the injury site days or weeks after the primary injury. Spinal cord swelling is not well understood. It has been observed clinically and in animal models but has never been directly quantified [1-3]. The purpose of this study was to evaluate the feasibility of using fiber optic pressure sensors to directly quantify swelling as a function of pressure in the spinal cord in our established *in vivo* porcine model of SCI.

II. METHODS

Fiber optic pressure sensors are suitable for *in vivo* measurements because they are electrically stable, can operate at body temperature, are highly biocompatible, small in size, and resistive to harsh chemical environments. In this investigation we used Samba fiber optic pressure sensors (Samba Preclin 420, Harvard Apparatus Canada, QC[4]) to measure the pressure within the spinal cord. These sensors are designed to measure pressure in gas and liquid; however, the spinal cord is comprised of both fluid and structural elements, such as nerve fibers, and is characterized as a soft biological material. Therefore, we hypothesize that the sensors may not be measuring fluid pressure but measuring a quantity proportional to bulk stress in the cord instead.

To evaluate the feasibility of using these sensors, we conducted *ex vivo* tests in which two fiber optic pressure sensors were inserted into the spinal cords of seven pigs. During these tests, a point load was applied to the spinal cord by placing a 9 mm diameter cylindrical impactor with rounded edges onto the spinal cord. After measuring baseline pressure for 5 minutes, the impactor (14 grams) was placed on the spinal cord. The load was then increased every 5 minutes by adding weights onto the impactor in 20 gram increments. In 10 trials the distance between the sensor and the load site was varied in order to identify an appropriate placement of the sensor such that pressure increases could be detected. In the four subsequent trials the “best case” distance identified from the previous animals was used. These tests were done within four hours of euthanasia.

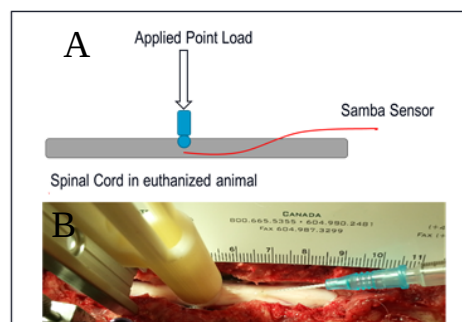


Figure 1: *Ex vivo* test set-up to measure pressure while applying a point load.
A. Schematic of Components and B. Picture of set-up.

III. INITIAL FINDINGS

We found that the measured pressure increased non-linearly with increasing mass and returned to baseline once all mass was removed (A, Figure 2 and 3). The distance from the load site affected the magnitude and sensitivity of the pressure measurements (Figure 2). It was found that the best signal was obtained at a distance from the sensor tip to the center of the load site of 2-3mm. At this sensor position the pressure readings were similar across the different animals and trials (Figure 3).

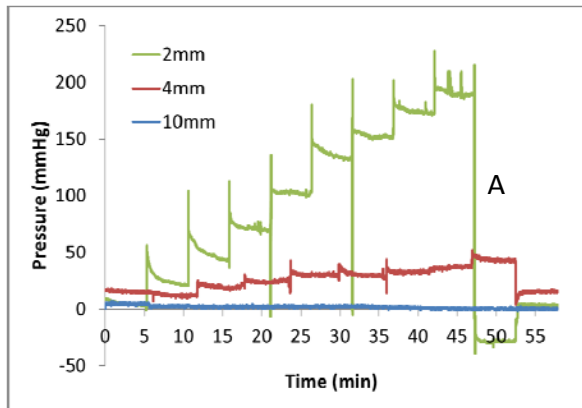


Figure 2: The effect of distance of the sensor from the center of the load site while measuring pressure. A. Weight was removed.

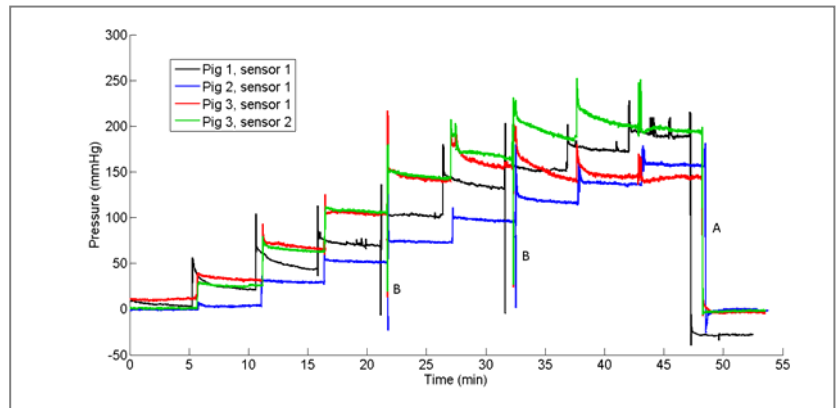


Figure 3: Pressure readings with sensor placed 2-3mm from the center of the load site. A. Weight was removed and B. Spikes caused by changing the weight.

IV. DISCUSSION

The pressure in the spinal cord was seen to decrease over each 5-minute interval in Figure 3, even though the stress on the cord was held constant. This behaviour is similar to the fluid phase pressure observed in creep tests of biphasic materials such as cartilage [6]. We think the spinal cord can be interpreted as a biphasic material since it is composed of both solid and fluid elements. This comparison leads us to believe we are measuring the fluid phase pressure in the spinal cord.

We believe that applying a hydrostatic pressure to the spinal cord would be more representative of the *in vivo* situation than applying a point load; therefore, in the future we will conduct another *ex vivo* test where we will apply a hydrostatic pressure to spinal cord segments using a fluid pressure tank. We will measure the pressure in the spinal cord as well as in the fluid tank, as shown in Figure 4.

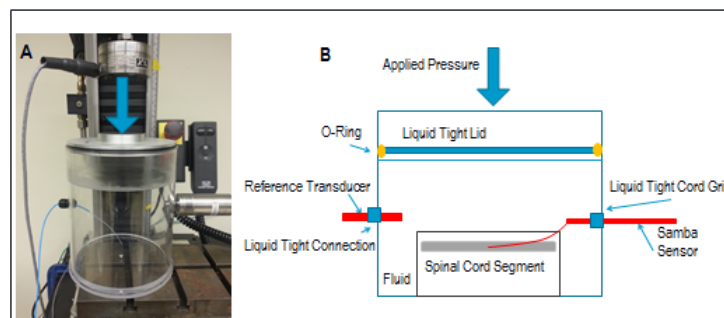


Figure 4: Pressure tank set-up for applying hydrostatic pressure to cord segment. A. Picture of set-up and B. Schematic of components

We expect to find a relationship between applied and measured pressures which will allow us to use fiber optic pressure sensors in the spinal cord to measure swelling pressure *in vivo*. By quantifying swelling, we hope to contribute to the understanding of spinal cord swelling and its effects on spinal cord injury outcomes.

References

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