DEVELOPING A METHOD TO QUANTIFY SPINAL CORD SWELLING USING FIBER OPTIC PRESSURE SENSORS

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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, 2, 3]. The purpose of this study was to develop a method to directly quantify swelling as a function of pressure in the spinal cord using fiber optic pressure sensors in our established in vivo porcine model of SCI.

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) 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.

RESULTS AND DISCUSSION
We found that the measured pressure increased non-linearly with increasing mass and returned to baseline once all mass was removed (A, Figure 2). The distance from the load site affects the magnitude and sensitivity of the pressure measurements. 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 readings were similar across the different animals and trials (Figure 2).

The pressure in the spinal cord is seen to decrease over each 5 minute interval in Figure 2, even though the stress on the cord was held constant. This behavior is similar to the fluid phase pressure observed in creep tests of other biphasic materials such as cartilage [6]. 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.

By quantifying swelling, we hope to contribute to the understanding of spinal cord swelling and its effects on spinal cord injury outcomes.

REFERENCES
4. Samba Preclin 420, Harvard Apparatus Canada, QC