Nerve Tensiometer for Spondyloptosis Surgery

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***Abstract*— Spondyloptosis is a type of severe spinal deformity that develops during childhood and progresses to adulthood. Spondyloptosis causes back pain, limited range of mobility, leg weakness and severe hamstring tightness. Correction of spondyloptosis requires careful preoperative analysis and special surgical techniques to ensure optimal nerve root stretch; both under-stretch and over-stretch pose a danger to the patient. In this paper, we describe a tensiometer useful for predicting impending nerve injury during spondyloptosis surgery.**

I. Introduction

We hypothesize that measuring tension in nerve roots will improve the safety of spondyloptosis correction surgery. Spondyloptosis is a spinal deformity wherein the lumbar spine shifts forward relative to sacrum and can become completely dislocated, falling into the pelvis (see Fig. 1). Predisposing factors include congenital malformation of the spine at the lumbo-sacral junction, or a L5 stress fracture during childhood.

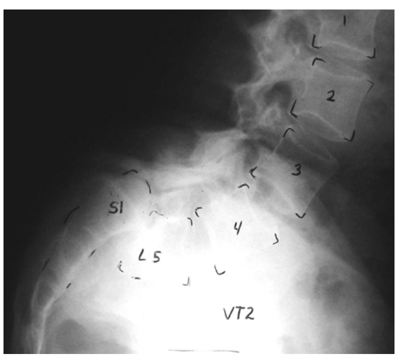


Fig 1. Spondyloptosis; the misalignment of the S1 and L5 vertebrae.

Correction of spondyloptosis requires careful preoperative analysis and extensive experience since there is no way to objectively quantify excessive L4 and L5 root stretch. Gradual Posterior Instrumented Reduction (GPIR) can achieve full correction of spondyloptosis in fewer surgical sessions compared to alternative methods [1], but it does not remove the requirement of nerve elongation during corrective surgery. Thus, we propose to augment the GPIR procedure with a tensiometer for objectively monitoring nerve root stretch during surgery. The tensiometer is able to measure both the force and the displacement of the nerve root. We expect this information to be useful in determining nerve root elongation limits. Currently, such limits are set using heuristics based on patient age, duration of deformity, L-S kyphosis, lumbar flexibility, and the number of previous surgeries [1,2,4]. Surgical experience has indicated that safe levels of nerve elongation range from 2 to 5 *cm.*

II. Electrical and Mechanical Design

The purpose of tensiometer is to measure both the force and the displacement of a nerve root during surgery. The mechanical design consists of a load cell to measure forces, a linear stage to measure displacement and a cabling and hook subsystem to transfer the force. The linear stage is attached to a passive arm to ensure that the hook is perpendicular to the nerve root cross section, as shown in Fig. 2. The lockable arm is a standard passive positioning arm that provides the necessary degrees of freedom to enable the surgical team to place the hook directly above the nerve, with the load cell aligned toward the nerve. The load cell (Entran ELFS) has a range of 5lbs and a resolution of 42.2 mV/lb. The linear stage consists of a micrometer stage (Daedal Inc. MX25) with a maximum travel of 25 mm.

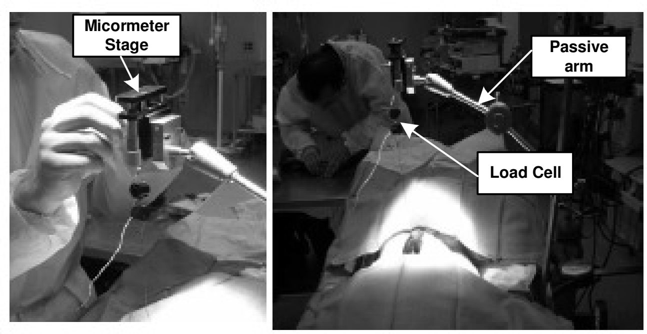


Fig. 2. The nerve tensiometer during the animal experiment

The electrical board of the tensiometer is an instrumentation amplifier. Electrical screening was accomplished using an oscilloscope for the experiments reported in Sec. 3, but a computer interface and software are available for future experiments. The interface board and computer software will provide real-time intraoperative data processing.

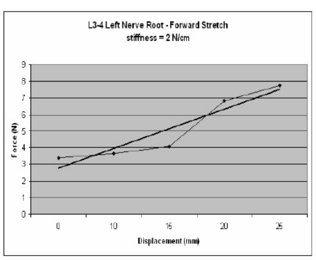
III. Animal Experiment Results

An animal experiment was performed at the Minimally Invasive Surgery Training Center (MISTC) at Johns Hopkins

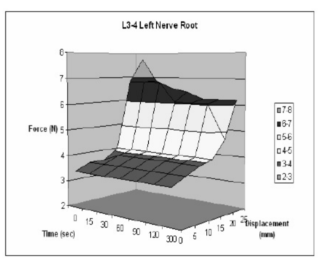
University on a porcine model. The pig was first used in (unrelated) standard training laboratories for surgical residents, after which it was euthanized per standard protocol. Thus, our research required no direct animal sacrifice. Immediately following euthanization, we performed following experiments on the fresh pig cadaver. With the pig prone on the surgical table, it was draped to isolate the lumbar region. A midline incision was made with a scalpel through the skin from the spinous processes of L2 proximally to L4 distally. After locating the lumbar fascia, it was dissected at the midline. Using the scalpel, the facets joints at L2-3, L3-4 and L4-5 were exposed and facet capsules were removed. A laminectomy was performed using a wide rongeur and adequate access to the nerve was created by removing facets. The tensiometer hook was then placed under the nerve.

The tensiometer provided displacement-voltage readings. After aligning the load cell with the hook on nerve root (with the hook perpendicular to the nerve root cross section), the nerve root was stretched by displacing the linear stage and the output voltage was recorded. Force measurements were collected for 5 *mm* displacement intervals, and the following measurements were collected:

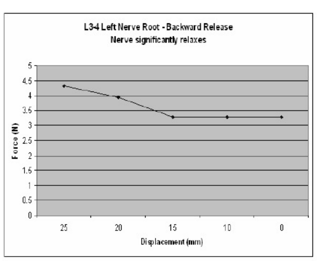
1) L3-4 Left nerve root forward stretch, immediately after displacement, Figure 3(a)
2) L3-4 Left nerve root stretch with time (nerve relaxation vs. time), Figure 3(b)
3) L3-4 Left nerve root release, after 2 minutes (nerve relaxation), Figure 3(c)



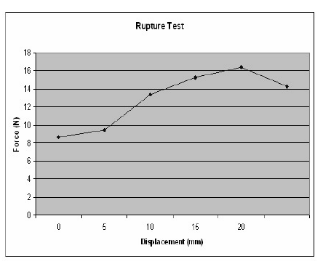
(a) Nerve root stretch



(b) Nerve stretch profile vs. time



(c) Nerve relaxation



(d) Rupture test

Fig. 3. Animal Experiment Results

4) Left nerve root stretch for second time after 5 minutes (repeatability test)
5) L3-4 Right nerve root stretch with time (consistency test)
6) Rupture test; the passive arm was first moved by hand and fixed such that the force sensor read the maximum voltage seen in prior measurements , and then the linear stage was moved until the nerve ruptured, Figure 3(d).

The results shown in Fig. 3 indicate that the nerve roots relax significantly after initial displacement. The reaction force of the nerve at maximum displacement (25 *mm*) dropped by 3.5 *N* after about two minutes. The stiffness of the nerve was found by fitting a line to measured data and for the first measurement above was 2 *N/cm*. Note that the force being measured by the tensiometer is not the same as the tension along the longitudinal axis of the nerve. Parameters such as stress, strain and tension of the nerve root can be calculated after determining the nerve root diameter, length, and boundary conditions, and this is a topic for future research.

IV. Conclusion

Spondyloptosis is spine a severe spine deformity which causes back pain, limited mobility and leg weakness. We have described a nerve tensiometer capable of measuring forces and displacement of nerve roots. These measurements along with nerve root dimensions will allow determination of biomechanical properties of nerve roots, such as stress, strain and elasticity. The device may improve the safety of spondyloptosis surgery by ensuring safe levels of tension are applied.

Future work aims toward the development of a correlation function for intraoperative real-time determination of root lengthening limit. Force measurement using a multi-DOF sensor and replacing the passive arm with a robotic manipulator are the future components of an enhanced overall system. Moreover, augmenting the system with a data acquisition board to enable PC data input will enable real-time processing of measured data.

Acknowledgement

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