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Effect of Arching Spine on Deformation of the Ligamentum Flavum during Epidural Needle Insertion*

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Abstract— **When administering epidural anesthesia, anesthesiologists ask patients to arch their back. Arching the spine is thought to enlarge the gap between neighboring vertebral bones. The author hypothesized that tension inside the ligamentum flavum generated by arching the spine would reduce deformation of the ligamentum flavum during epidural needle insertion. Porcine spines from a slaughterhouse were cut at the vertebral body and separated into 10 pieces. Ligamentum flavum was painted black with liquid ink. A CCD camera recorded the deformation of the ligamentum flavum during needle insertion. To simulate the arching spine, the width of the ligamentum flavum was enlarged by a retractor. The thickness of the ligamentum flavum was measured from the stained images by the Elastica-van Gieson method. The maximum reaction force showed no significant difference between the natural and the enlarged ligamentum flavum. Average deformation was observed a statically significant decrease between the naturally deformed and retractor-enlarged ligamentum flavum. For the maximum reaction force the coefficient of variance decreased by dividing raw data with thickness of the ligamentum flavum, which meant that the maximum reaction force correlated with thickness of the ligamentum flavum. Less effect on deformation was observed. Hypothesis was correct in the porcine study, while the difference between the porcine and the patient's spine should be examined in the next research.**

Key Words: Epidural anesthesia, Ligamentum flavum, Needle insertion, Deformation, Arching the spine

I. Introduction

Epidural anesthesia is regional anesthesia that blocks pain in a particular region of the body, and the goal of using epidural anesthesia is to provide pain relief. Epidural anesthesia blocks the nerve impulses from the lower spinal segments, resulting in decreased sensation in the lower half of the body [1].

When administering epidural anesthesia, anesthesiologists ask patients to arch their back and remain still while lying on their left side. An epidural needle is then inserted into the numbed area that surrounds the spinal cord in the lower back. A catheter is threaded through the needle into the epidural space. The needle is carefully removed, leaving the catheter in place, so medication can be given through periodic injections or by continuous infusion into the catheter.

Less than 1% of patients experience a severe headache caused by leakage of spinal fluid resulting from dural punctures by an epidural needle. Anesthesiologists must stop insertion by feeling a drop of the force needed to insert the needle, when the needle tip passes through the ligamentum flavum. Difficulties of inserting the needle into the epidural space are 1) blind needle tip placement, 2) narrow epidural space up to 6 mm, and 3) elasticity of the ligamentum flavum. Vallejo et al. reported from a prospective, randomized, non-blinded study that ultrasound measurement of the epidural space depth before the epidural needle insertion decreased the rate of epidural catheter replacements for failed labor analgesia and reduced the number of epidural attempts when performed by first year residents, compared to attempts without ultrasound guidance [2]. However, no significant differences were noted with respect to accidental dural punctures. The author has reported, in experimental results with porcine spines that the ligamentum flavum deforms up to 3mm before the needle tip reaches the epidural space [3]. Length of the needle tip is more than 2 mm. As shown in Fig.1, deformation of the ligamentum flavum increases possibility to occur dural puncture. If deformation of the ligamentum flavum can be reduced, the number of dural punctures would hardly occur.

In the current study, the author focused on the arching of the patient's spine during epidural needle insertion. Arching the spine is thought to enlarge the gap between neighboring vertebral bones. The author hypothesized that tension inside the ligamentum flavum generated by arching the spine would reduce deformation of the ligamentum flavum during epidural needle insertion. The purpose of the present study was to test this hypothesis.

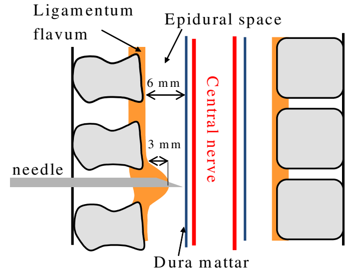

Figure 1.
Explanation for increasing possibility for dural puncture due to the deformation of the ligamentum flavum

II. Material and Methods

A. Experimental setups

Porcine spines from a slaughterhouse were cut at the vertebral body and separated into 10 pieces. After trimming the interspinous ligament, the remaining ligamentum flavum

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was 3 mm thick. Each piece of porcine spine was fixed to a plastic frame by screws. To simulate in vivo tissue, test pieces were warmed at a constant temperature of 35 degrees Celsius. Surface temperature was measured by a non- contact infrared type sensor.

Ligamentum flavum was painted black with liquid ink. A CCD camera recorded the deformation of the ligamentum flavum during needle insertion.

The 18G epidural needle and a load cell were put on a stage of a linear actuator, and the needle was inserted into a test piece by moving the stage of the linear actuator. The insertion speed was 12.5 mm/sec. Sampling interval of the force was set at 0.0125 second.

B. Simulating arching spine

To simulate the arching spine, a retractor was employed as shown in Fig.3. The width of the ligamentum flavum was enlarged by the retractor. The maximum reaction force as insertion resistance and the maximum deformation of the ligamentum flavum were measured and compared between the natural ligamentum flavum and the ligamentum flavum enlarged by the retractor.

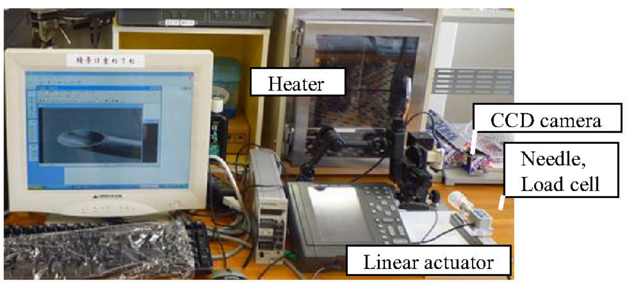
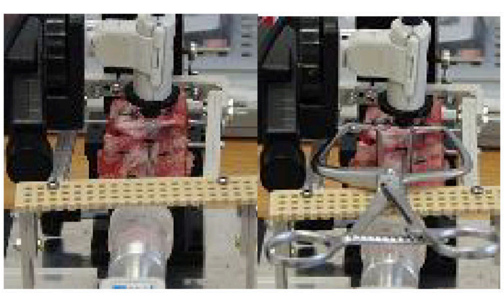


Figure 2.
Photo of the experimental setups

Figure 3.
Small size retractor employed to simulate the arching spine



(i) Before enlargement (natural) (ii) enlarged

Figure 4.
Explanation of the method to enlarge the ligamentum flavum

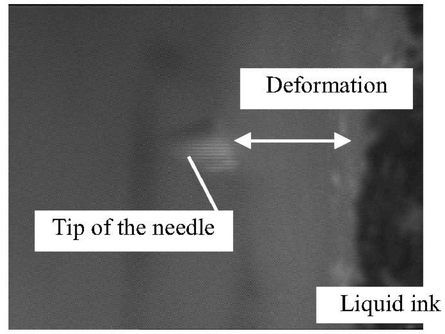


Figure 5.
CCD image of the ligamentum flavum painted by liquid ink and explanation of the maximum deformation.

C. Elastica-van Gieson method

Test tissues were immersed in formalin solution and fixed with paraffin after the experiment. Thin slices of the paraffin-embedded tissue were stained by the Elastica-van Gieson method. The ligamentum flavum appears as a brown layer in the stained images. The thickness of the ligamentum flavum was measured.

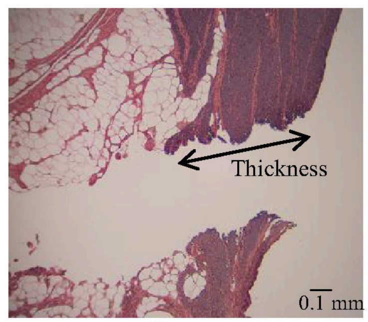


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Figure 6.
Elastica-van Gieson image of the ligamentum flavum

III. RESULTS

The results are shown in Fig.7. The maximum reaction force showed no significant difference between the natural and the enlarged ligamentum flavum. In the ligamentum flavum enlarged by a retractor, the average deformation of the ligamentum flavum was 1.4 mm, while the average deformation of the natural ligamentum flavum was 4.2 mm. A statically significant decrease was observed between the naturally deformed and retractor-enlarged ligamentum flavum.

The enlarged ligamentum flavums were divided into thoracic and lumbar spine. Comparison of the maximum reaction force and deformation of the ligamentum flavum are shown in Fig.8 (i). Thickness of the ligamentum flavum was different among species. Thickness of thoracic ligamentum flavum was 1.9 mm in average, whereas 0.57 mm in average for lumbar ligamentum flavum. Thoracic ligamentum flavums were more than three times thicker than lumbar ligamentum flavums. Each value of the maximum reaction force and deformation of the ligamentum flavum was divided by the thickness of the ligamentum flavum as shown in Fig.8 (ii). The maximum reaction force divided by thickness of the ligamentum flavum was significantly different between thoracic and lumbar spines as our previous study.

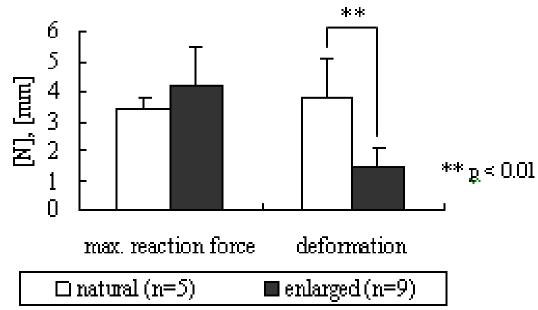
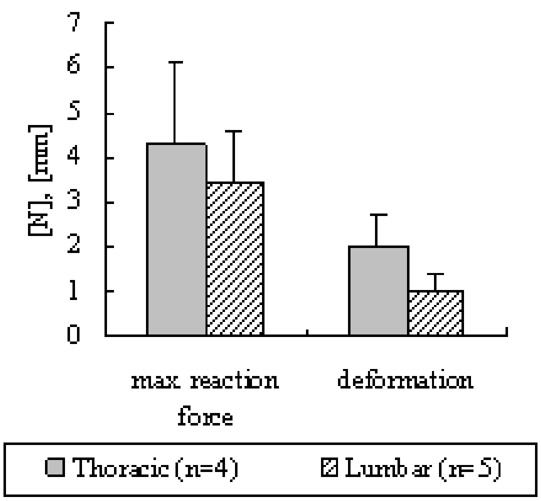
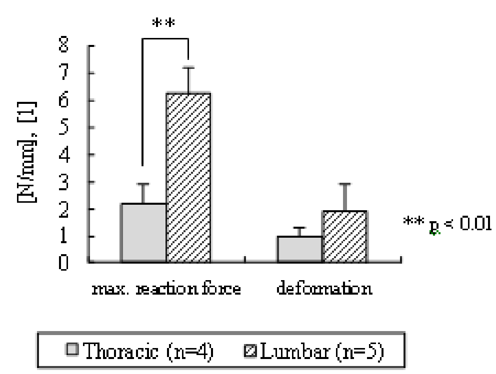


Figure 7.
Comparison of the maximum reaction force and the deformation of the ligamentum flavum between the natural and the enlarged spines



Raw data



Raw data divided by thickness of the ligamentum flavum

Figure 8.
Comparison of the maximum reaction force and the deformation of the ligamentum flavum between thoracic and lumbar spines under the enlarged ligamentum flavum

IV. DISCUSSION

A. *Anatomical comparison between human and porcine ligamentum flavum*

In this experiment, porcine spines were employed as substitutes for human patients. Cadaver study has shown the shape of the human ligamentum flavum, as follows. Thickness ranged from 3.5-6 mm [4], 3-5 mm [5]. Width ranged from 11-23 mm [4], 12-22 mm [5]. Height ranged from 14 to 22 mm. In the case of the porcine spines, the thickness was 1.7±0.4 mm based on the Elastica-van Gieson stained image. Height ranged from 2 to 7 mm. Width could not be measured. Porcine ligamentum flavum was thinner and smaller than human ligamentum flavum. Numerical simulation will be useful to clarify the effect of the anatomical difference on deformation of the ligamentum flavum. The author previously reported a finite element analysis of this difference [6]. The shape of the human ligamentum flavum was modeled as a square plate 5 mm in width and 5 mm in height, while the shape of the porcine ligamentum flavum was modeled as a square plate 1 mm in width and 5 mm in height. For simplicity, a constant load of 10 N was applied at the center of each model. The porcine model exhibited deformation 1.7 times that of the human model. The porcine ligamentum flavum is an enhanced model to simulate the human ligamentum flavum.

B. *Range of motion of the spine*

Patients arch their back during epidural needle insertion. Range of motion of the human spine is essential for selecting conditions for in vitro experiments. Xia et al. validated a combined dual fluoroscopic and MRI/CT imaging system to investigate in vivo lumbar spine kinematics in human subjects [7]. Interspinous process distance changes that occurred while going from the flexion to the extension positions were determined as L2–3 = 4.5 ± 4.8, L3–4 = 4.1 ± 5.0, and L4–5 = 2.0 ± 2.3 mm. In the current experiment, porcine spine was enlarged up to 3 mm. Enlargement remained within the human physiological range of motion of the spine.

C. *Effect of dividing raw data with thickness of the ligamentum flavum*

As shown in Fig.8, statistical difference between thoracic and lumbar ligamentum flavum was changed by dividing raw measured data with thickness of the ligamentum flavum. Table shows calculated coefficient of variance (CV). For the maximum reaction force the CV value decreased by dividing raw data with thickness of the ligamentum flavum, which meant that the maximum reaction force correlated with thickness of the ligamentum flavum. Less effect on deformation was observed.

In the current experiment, enlargement of the ligamentum flavum by a retractor was set arbitrarily without considering width of the natural ligamentum flavum. Initial strain given inside the ligamentum flavum differed for each specimen. Author will measure the width of the ligamentum flavum before and after enlargement by a retractor.

TABLE I. COMPARISON OF THE COEFFICIENT OF VARIANCE IN THE MAXIMUM REACTION FORCE AND DEFORMATION OF THE LIGAMENTUM FLAVUM BETWEEN THE THORACIC (T) AND THE LUMBAR (L) SPINES. EFFECT OF DIVIDING RAW MEASURED DATA WITH THICKNESS OF THE LIGAMENTUM FLAVUM IS ALSO SHOWN.

T	**Force [N]**	**Force/ Thickness [N/mm]**	**Deform-ation [mm]**	**Deformation /Thickness [1]**
Mean	4.3	2.2	2.0	1.0
SD	1.8	0.69	0.67	0.31
CV [%]	42	31	34	31

L	**Force [N]**	**Force/ Thickness [N/mm]**	**Deform-ation [mm]**	**Deformation /Thickness [1]**
Mean	3.4	6.2	1.0	1.9
SD	1.1	0.97	0.4	1.0
CV [%]	32	16	40	53

V. CONCLUSION

Effect of arching spine during the epidural needle insertion was examined by experiments using the porcine spines and a retractor. Deformation of the enlarged ligamentum flavum before the needle puncture decreased in comparison with the natural ligamentum flavum.

ACKNOWLEDGMENT

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REFERENCES

[1] http://www.americanpregnancy.org/labornbirth/epidural.html

[2] M. C. Vallejo, A. L. Phelps, S. Singh, S. L. Orebaugh, N. Sah, “Ultrasound decreases the failed labor epidural rate in resident trainees.”, *Int J Obstet Anesth.*vol.19, no.4, pp.373-378, 2010

[3] K. Naemura., H. Saito, “ Needle Insertion Test by Porcine Ligamentum Flavum”, in: IFMBE Proceedings of WC 2009, vol. 25 /VI, pp. 28–31

[4] E. M. Abdel-Meguid, “An anatomical study of the human lumbar ligamentum flavum”, *Neurosciences*, vol.13, no.1, pp.11-16, 2008

[5] E. Zarzur, “Anatomic studies of the human lumbar ligamentum flavum”, *Anesth Analg*, vol.63, pp. 499-502, 1984

[6] K. Naemura, “Young’s modulus measurement of the porcine ligamentum flavum for evaluating the deformation during epidural insertion”, in: Conf. Proc. IEEE Eng. Med. Biol. Soc. 2010, pp. 3923–3925

[7] Q. Xia, S. Wang, P. G. Passias, M. Kozanek, G. Li, B. E. Grottkau, K. B. Wood,G. Li, “In vivo range of motion of the lumbar spinous processes”, *Eur Spine J*.vol.18, no.9, pp. 1355–1362, 2009