Effect of Spinal Cord Stretching due to Head Flexion on Intramedullary Pressure

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Abstract

The effect of the longitudinal stretching force of the spinal cord on intramedullary pressure was investigated using our method for measuring intramedullary pressure of the spinal cord with implanted balloons. The transverse compressive force against the posterior wall of the spinal column was excluded by measuring the intramedullary pressure during flexion of the head with the middle and lower cervical spine in the neutral position. The intramedullary pressure of the cervical spinal cord was measured simultaneously at the C-2, C-4, and C-6 levels in 10 mongrel dogs, in three head positions: neutral, and head extension and flexion. Head flexion caused significant increases in the intramedullary pressure at C-2, C-4, and C-6. The pressure increase in the middle to lower cervical cord must have been due to the transmission of the longitudinal stretching force of the cord itself, and may be a factor in the development of intramedullary disorders such as syringomyelia and intramedullary neoplasms.

Key words: biomechanics, intramedullary pressure, cervical spine, spinal cord, syringomyelia

Introduction

Analysis of the biomechanics of the spinal cord is important to clarify the pathophysiology of progression of intramedullary spinal cord disorders. For example, noncommunicating syringomyelia may be caused by mechanical forces in the spinal cord.1,2,5,6,9-12 The sum of the forces in the spinal cord must change with the craniocervical dynamics, since the cervical spinal cord undergoes significant changes in length during flexion and extension.3,4,7,8

Measurement of the intramedullary pressure is the only method for investigating the sum of the three-dimensional forces within the pia of the spinal cord. We previously described a method to measure intramedullary pressure experimentally in vivo10 which allows real-time pressure measurement following craniocervical movement. We found the pressure was increased in the cord at C-5 and C-6 with the entire neck in the flexed position. The increased intramedullary pressure is caused by two forces, acting in different directions: a longitudinal stretching force in the cord itself and a transverse compressive force holding the cord against the posterior wall of the spinal column. This study investigated the effect of the longitudinal stretching force alone, independent of the direct compressive force, upon the intramedullary pressure.

Materials and Methods

Balloons to measure the intramedullary pressure were prepared as described previously.10 The balloons were 1.45 mm in diameter, 10 mm in length, and 60 μm thick. The reliability of each balloon was tested as described before.10

Ten adult mongrel dogs, four females and six males weighing 10–12 kg (mean ± SD 11.3 ± 1.2 kg), were anesthetized by intravenous administration of sodium pentobarbital (25 mg/kg), immobilized by intravenous administration of pancuronium bromide (0.1 mg/kg), intubated, and ventilated using a respirator (SN-480-3; Shinano, Tokyo). The systemic arterial pressure was monitored throughout the experiment by means of a catheter inserted into the femoral artery. Laminectomies from C-1 to C-7 were performed with the animal fixed in the prone position.
position with a stereotactic device (1504; Davidcopf Instruments, Tujunga, Cal., U.S.A.). The dura was opened, a midline cordotomy reaching the anterior commissure was made at the levels of the C-2, C-4, and C-6 vertebrae, and a latex balloon was embedded at each level. Then, the pia was sutured using 10-0 monofilament nylon. The dura mater was left open to prevent any influence from dural tension or cerebrospinal fluid pressure. The balloons were filled with 12 μl of distilled water and connected to a pressure transducer (P50; Nihon Koden Co., Tokyo) through 2 Fr catheters. The dogs were then removed from the stereotactic device and placed in a lateral position.

While the middle to lower cervical spine was kept in the neutral position, a roentgenogram was taken with the head in three positions: neutral, head extension, and head flexion. The rotatory deviation angles in the sagittal plane between head positions were measured in the following manner (Fig. 1). First, the reference lines of each vertebra and the occiput were selected: the line along the posterior wall of each vertebra for C2-T1 levels, the line along the anterior surface of the wing for C-1, and the line joining the center of the external acoustic meatus to the external occipital protuberance for the occiput. The reference line of T-1 was chosen as the basic reference line, so that, taking $\theta$ as the angle between this line and another reference line, the rotatory deviation angle ($\Delta \theta$) was calculated by subtracting $\theta$ (in the neutral position) from $\theta$ (in head extension or flexion). Thus, $\Delta \theta$ was a relative not an absolute value, and so was not affected by the selection of the reference lines, and the value was independent of where the measurement was made. The rotatory deviation angles in the sagittal plane are plotted on Fig. 2. Almost the entire range of motion was accounted for by flexion or extension between the occiput and C-3. The total dynamic range between head extension and flexion below C-4 was only 7 degrees, while the total dynamic range of the entire cervical spine and occiput was 105 degrees, indicating that the middle to lower cervical spine remained almost completely in the neutral position during the motions made in this study.

The intramedullary pressures for each head position were measured at each level simultaneously. Since the plateaus of the pressure changes occurred immediately following the positional alteration, as described in our previous paper, all measurements were done within 10 seconds of the head being placed in each of the three positions. All dogs were killed while still under anesthesia at the termination of each investigation.

The significance of differences in the pressures at each level between the neutral head position and the flexed and the extended head positions was determined using the paired t-test. Analysis of variance was used to ascertain the inter-level pressure differences.
Results

The intramedullary pressures measured in the neutral posture at C-2, C-4, and C-6 were 18.9 ± 3.8, 19.3 ± 2.3, and 20.2 ± 3.7 mmHg (mean ± SD, n = 10), respectively. There was no statistically significant inter-level difference. In head extension, the pressures at C-2, C-4, and C-6 were 21.1 ± 6.8, 20.5 ± 3.6, and 20.5 ± 4.7 mmHg, respectively. No significant change from the neutral head position pressure was observed at any level. However, in head flexion, the pressures at C-2, C-4, and C-6 were 34.2 ± 9.1, 28.7 ± 4.3, and 26.4 ± 5.3 mmHg, respectively. There were statistically significant increases (p < 0.001 at C-2, p < 0.01 at C-4 and C-6).

The mean pressure increases during head extension were 2.2 ± 1.1 mmHg at C-2, 1.2 ± 0.9 mmHg at C-4, and 0.3 ± 0.6 mmHg at C-6 (mean ± SE, n = 10), with no statistically significant difference. The pressure increases in head flexion were 15.3 ± 2.8 mmHg at C-2, 9.4 ± 1.7 mmHg at C-4, and 6.2 ± 1.3 mmHg at C-6, showing a statistically significant increase at C-2 (the maximum) compared with that at C-6 (p < 0.01). The pressure increase at C-4 was 61.4% of that at C-2, and that at C-6 was 40.5%.

Discussion

Cranio cervical dynamics are thought to be an important factor in the creation of a harmful force resulting in a spinal cord structural insult in patients with some types of intramedullary lesion. Breig performed dissections of cadavers and dynamic air myelograms of patients, and found that, when the cervical spinal column was flexed, the cervical spinal canal elongated resulting in stretching and shortening the cord, and extension of the cervical column caused the cord to relax and shorten. With the whole neck flexed, the cord stretching directly produces a longitudinal force, and a transverse force due to increased tension of the cord riding over the posterior wall of the vertebral bodies. Our previous study found increases in intramedullary pressure are a function of the sum of the three-dimensional forces inside the cord, made up of these longitudinal and transverse forces.

The present study investigated restricted cranio-upper cervical motion, in which the pressure measurement point was distant from the skeletal motion. This method eliminated the influence of the direct compressive force of the cord against the posterior wall of the spinal column. The pressure change was measured at the middle to lower cervical cord with head flexion, but without flexing of the whole cervical spine. Motion was maximum at the occiput to high cervical vertebrae, with minimal movement of the middle to lower cervical vertebrae. We found that the sum of the axial rotation at and below the C3-4 joint was less than 7 degrees, which was thought to be negligible. Therefore, stretching of the cord over the vertebrae was observed only in the high cervical segments, not at C-4 or at C-6.

The sum of the longitudinal stretching force of the cord and the transverse direct compressive force in head flexion cause the increase in intramedullary pressure at C-2. However, significant pressure increases were also observed at C-4 and at C-6. The increase in pressure at C-4 reached 9.4 mmHg, and that at C-6 was 6.2 mmHg. These pressure increases in the middle and lower cervical cord are most likely to be the result of longitudinal transmission of the stretching force from the high cervical region. This suggests that the longitudinal stretching force alone can cause a significant increase in intramedullary pressure, which may result in the development of intramedullary disorders such as syringomyelia or intramedullary neoplasms.

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