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Assessment of Safety and Feasibility of Spinal Endoscope in the Thoracic and Lumbar Region: A Cadaveric Study

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BACKGROUND **Endoscope has been used far less in the spinal region than in the intracranial cavity. One of the reasons is its safety and feasibility has not been established. To evaluate its safety and feasibility, we performed preliminary cadaveric study prior to clinical endoscopic intervention in the thoracic and lumbar spinal canal.**

METHODS **The endoscope that had a directable tip with external diameters of 2.2mm was used in this study. The endoscope was inserted percutaneously in the lumbar region (lumbar puncture method) in nine cadavers and was advanced rostrally under endoscopic monitoring. In advancing the endoscope to the upper thoracic region, dorsal, lateral and ventral route was applied. When the endoscope was advanced to the upper thoracic region, vertebral canal from Th 1 to L4 was opened to examine whether there were any injuries to spinal cord and nerves.**

RESULTS **The endoscope could be manipulated and advanced under endoscopic image in the lumbar region. However, the filum terminale could not be detected under endoscopic view. In the thoracic region, the endoscope could be advanced in dorsal and lateral route. However, in advancing the endoscope in ventral route, the endoscope could not be advanced more rostrally. In cadavers that the endoscope was advanced in dorsal and lateral route, macroscopic and microscopic investigation revealed no injuries including compression marks or trace of cord were observed on the surface of the spinal cord and nerves.**

CONCLUSIONS **From this preliminary cadaver study, the safe route to advance the endoscope from the lumbar to the thoracic region was established and possibilities of clinical interventions in safe methods could be suggested.**

During recent years, endoscopic techniques have been refined and increasingly used in neurosurgery. It has been applied not only to the cerebral ventricles but also to the cranial cisterns and also skull base regions [2,4,10,20,22,23]. However, endoscope has been used far less in the spinal region than the intracranial cavity [24]. A previous report of ours concerned the clinical use of a small-0.5mm angiofiberscope in the spinal canal. However, that study focused on observation rather than intervention and a small 0.5mm angiofiberscope was used for that study [3]. To perform endoscopic intervention in spinal canal, endoscope should have larger diameter to create a proper treatment channel [3]. Therefore, the safety of this endoscope has not been established yet. In the study presented here, we performed preliminary cadaveric trial to assess the safety and feasibility of applying the 2.2mm endoscope in the thoracic and lumbar region.

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MATERIALS AND METHODS

The aim of this study was to establish the safety and feasibility of endoscopic application in the thoracic and lumbar region not only for observation but also for clinical intervention in a less invasive method. In the past, we had established the utility of endoscope via lumbar puncture for inspection of structures surrounding the spinal cord in cadaver study [3]. In that study, three types of endoscope were used: the AF-5 (an external diameter of 0.5mm), AF-14 (an external diameter of 1.4mm), and AF-22 (an external diameter of 2.2mm). While the first two endoscopes had rigid tips, the 2.2mm endoscope had a directable tip and one working channel. We considered the 2.2mm endoscope (Fig. 1) would be suitable for clinical interventions via lumbar puncture method. In this study, we used the angiofiberscope 22 (AF-22) (Olympus Tokyo, Japan) which had an external diameter of 2.2mm, an effective length of 1000 mm, a visual angle of 75^{o}, and an observation depth of 2 to 50mm. The tip of the AF-22 could be bent 120^{o} both upward and downward and had one channel. A cadaver study was performed on nine adult human cadavers with AF-22.

FIG. 1. The AF-22 had an external diameter of 2.2mm, an effective length of 1000mm, a visual angle of 75^{o}, and an observation depth of 2 to 50mm. The tip of the AF-22 could be bent 120^{o} both upward and downward and had one channel.

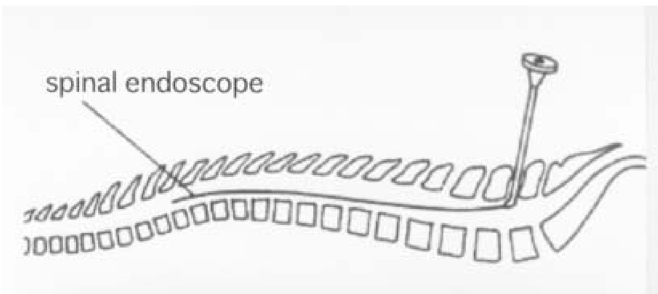

FIG. 2. Schematic illustration of endoscope inserted by lumbar puncture method.

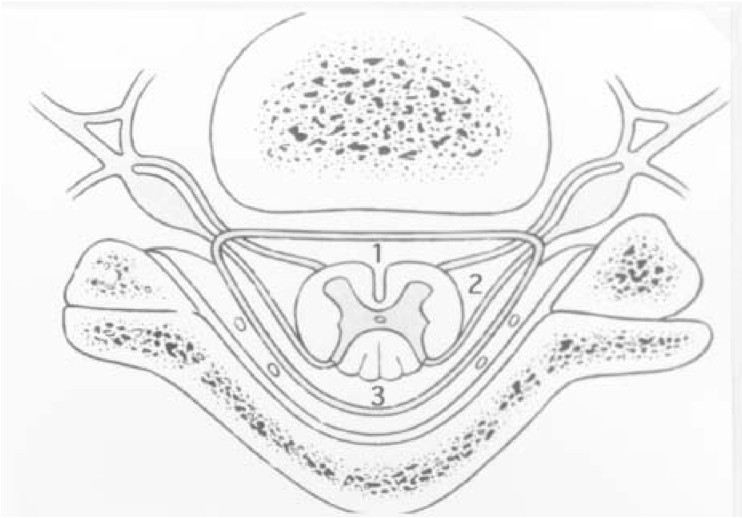

FIG. 3. Three route to advance the endoscope in thoracic region.
(1) ventral route. (2) lateral route. (3) dorsal route.

The AF-22 was inserted percutaneously from the lumbar region. First, a lumbar puncture was made at the level of L4-5 with a 20G angiocut needle. A guide wire was then inserted, and a 7Fr sheath (Terumo Company, Japan) that curved about 45^o was placed in the lumbar subarachnoid space. After the subarachnoid space was sufficiently perfused with physiologic saline, the AF-22 was inserted through the sheath under endoscopic monitoring and was guided to rostrally (Fig. 2). When the endoscope had been advanced to the upper lumbar region, three routes were applied to advance the endoscope in the thoracic region: (1) ventral route; the endoscope advanced in ventral side of the spinal cord. (2) lateral route; the endoscope advanced between anterior and posterior nerve root. (3) dorsal route; the endoscope advanced dorsal side of the spinal cord (Fig. 3). We applied three cadavers for each route. When the endoscope had been guided up to the upper thoracic region, the entire vertebral canal from Th 1 to L4 was opened to examine nerves as well as surface of the spinal cord where the endoscope had passed. Finally, the spinal cord was entirely removed for further macroscopic and microscopic examination.

RESULTS

The endoscope was inserted into the subarachnoid space of the cadavers by lumbar puncture. First, the cauda equina could be detected clearly and the endoscope was passed through it (Fig. 4). The 2.2-mm endoscope could be manipulated and advanced under endoscopic image to any desired site in the lumbar region, while avoiding nerve roots, because its tip could be bent 120^o in either direction. However, the filum terminale could not be detected under endoscopic view. When the endoscope was advanced in the upper lumbar region, anterior and posterior nerve root and their exit from the spinal canal could be visualized by rotating the tip of the endoscope laterally (Fig. 5). And also, the dentate ligament could be observed between anterior and posterior nerve root (Fig. 6). At the detection of the anterior nerve root, posterior nerve root, and dentate ligament, we advanced the endoscope in ventral (three cadavers), lateral (three cadavers) and dorsal route (three cadavers). The endoscope could be advanced as far as upper thoracic region without any resistance in lateral and dorsal routes in all six cadavers (Fig. 7). However, when the endoscope was advanced in ventral route, the resistance was so strong that the endoscope

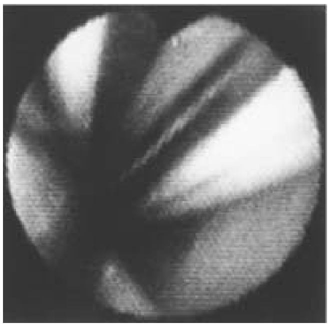 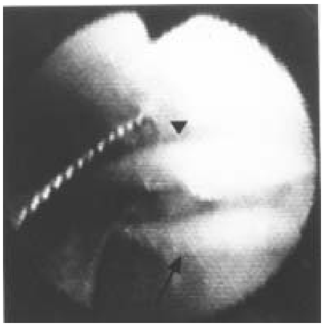 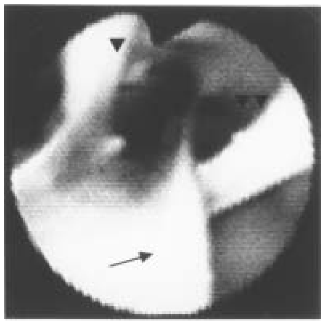

FIG. 4. (left) In lower lumbar region, endoscopic view revealed cauda equina.
FIG. 5. (middle) In upper lumbar region, the endoscope detected anterior (arrow); and posterior nerve root (arrowhead); and their exit from the spinal canal by rotating the tip laterally.
FIG. 6. (right) In upper lumbar region, anterior (arrowhead), posterior nerve root (arrowhead ×2) and dentate ligament (arrow) were detected.

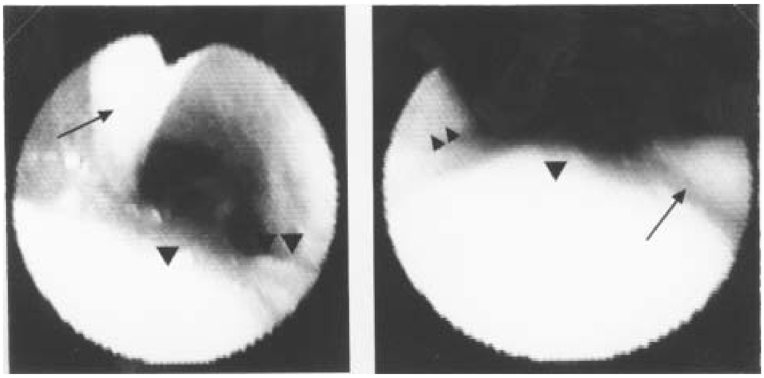

FIG. 7. In thoracic region, the endoscopic view in lateral route (a, left) and dorsal route (b, right). (a) Arrowhead (▼) indicated lateral surface of the spinal cord. Arrow (→) indicated rt. anterior nerve root of Th 5. Arrowhead×2 (▼▼) indicated rt. posterior nerve root of Th5. (b) Arrowhead (▼) indicated dorsal surface of the spinal cord. Arrow (→) indicated rt. posterior nerve root of Th 5. Arrowhead×2 (▼▼) indicated lt. posterior nerve root of Th5.

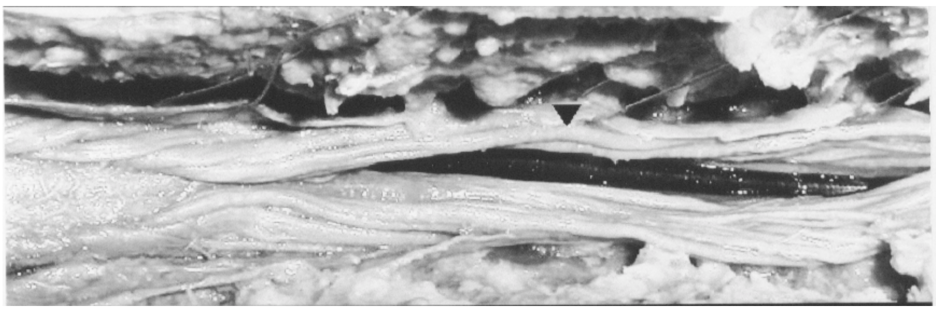

FIG. 8. Ventral canals were opened. The relationship between the endoscope and cauda equina was revealed. Macroscopic examination revealed no injuries to cauda equina. Arrowhead (▼) indicated cauda equina.

could not be advanced rostrally any further in all three cadavers. Therefore, in the thoracic region, the endoscope could be advanced in dorsal and lateral side of the spinal cord.

When the endoscope was guided to the upper thoracic region in ventral and lateral route under endoscopic view, the entire vertebral canal from Th 1 to L4 were opened, and the surface of the spinal cord of the cadavers and the root that endoscope had passed were examined. No injuries including compression marks or trace of cord damage on the ventral and lateral side of the spinal cord were observed and no nerves injuries were found in the route where the endoscope passed (Fig. 8, 9). After this procedure, the spinal cord was entirely removed and observed. No injuries to spinal cord and nerves were observed (Fig. 10). Microscopic examination also revealed there were no injuries to surface of the spinal cord (Fig. 11, 12).

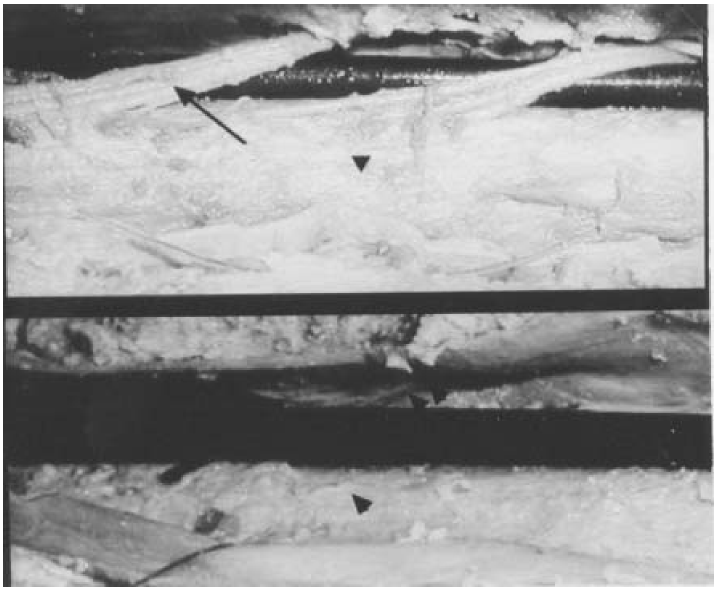

FIG. 9. The endoscope advanced in the lateral route (a, upper) and dorsal route (b, lower) without making injuries to nerve roots and surface of spinal cord.
(a) Arrow (→) indicated Rt. posterior nerve of Th4 and arrowhead (▼) indicated dorsal surface of the spinal cord.
(b) Arrowhead (▼) indicated dorsal surface of the spinal cord and arrowhead×2 (▼▼) indicated rt. posterior nerve of Th3.

DISCUSSION

Recently, cerebral endoscopic surgery has attracted attention as a minimally invasive operation, and endoscope has been applied not only to the cerebral ventricles but also to the cranial cisterns and skull base regions [2,4,10,20,22,23].

Endoscope of the spinal cord dates back to 1931, when Burman et al. [1] published the first paper regarding endoscope and the spinal canal, which has been follower by other publications [1,3,5, 7, 8, 11-19, 24, 27]. However, most of these publications were about endoscopic observation of spinal canal and its contents including pathological lesions using 0.5-3.8mm fiber endoscope. There was only just one publication that endoscopic intervention was performed[27]. In that report, they used 2.3mm fiber endoscope. They inserted the endoscope percutaneously from between L4 and L5 and coagulated part of spinal neurinoma in the thoracic region under endoscopic image. One of the reasons why spinal endoscope has not been used for clinical intervention is that endoscope should have larger diameter to have working channel in performing interventions, and its safety and procedural details have not been proven.

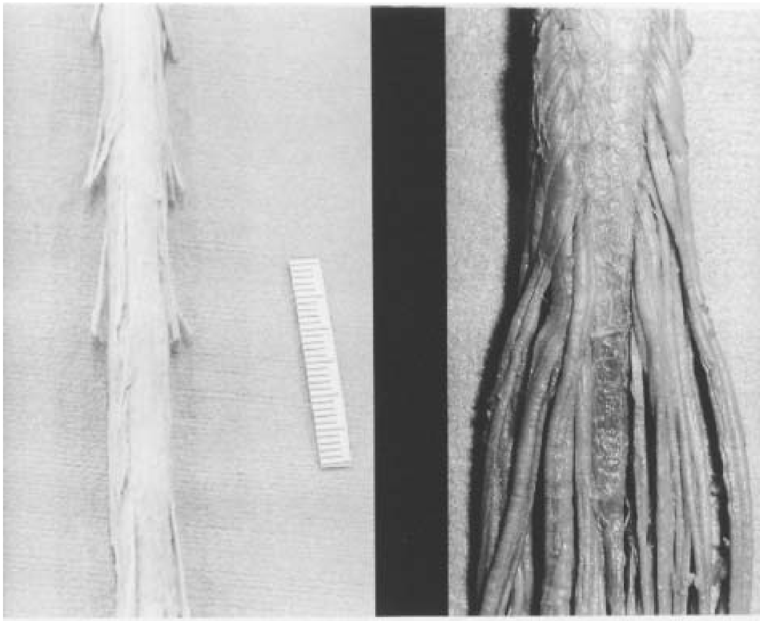

FIG. 10. The spinal cord removed after the procedure.
Macroscopic examinations revealed no injuries to nerves and surface of the spinal cord were detected.
(a, left) thoracic spinal cord. (b, right) lower part of lumbar spinal cord and cauda equina.

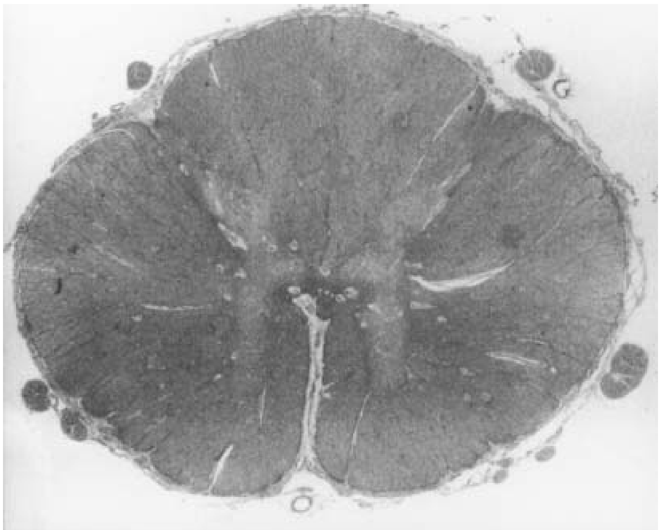

FIG. 11. Photomicrograph showing no injuries to the surface of the thoracic spinal cord.
HE stain, ×15.

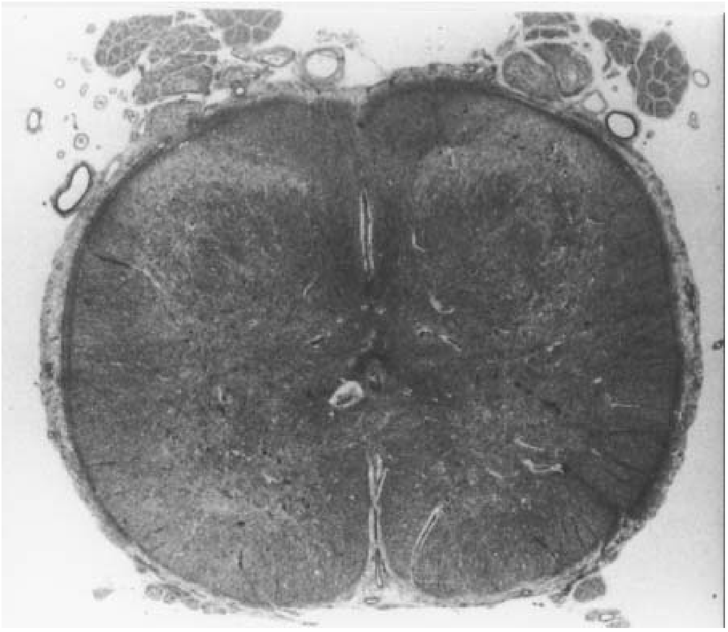

FIG. 12. Photomicrograph showing no injuries to the surface of the lumbar spinal cord. HE stain ×11.

To establish the safety in endoscopic procedure, no damage to normal structures should be demonstrated. In this study, to evaluate its safety and feasibility of applying endoscope in the thoracic and lumbar region, we used 2.2mm endoscope. The advantages of using this endoscope are:

(1) In clinical application, the 2.2mm endoscope could be inserted into subarachnoid space by lumbar puncture through the sheath, which has a valve to prevent the CSF flow out and is now available (Mizuho Company, Tokyo, Japan).

(2) The 2.2mm endoscope has a directable tip and one working channel.

(3) Although there have been a few studies about the size of the spinal subarachnoid space, Malinowsky has measured the size of the spinal ventral and dorsal subarachnoid space in the thoracic region. He found the distance in the thoracic region to be 1-3mm ventrally, dorsally 2-6mm, and in the lumbar region, ventrally 1-3mm, dorsally 2-7mm[6, 9]. Therefore, in using the endoscope in the thoracic and lumbar region safely, the external diameter of the endoscope should not exceed at least 3mm.

In the lower lumbar region, the endoscope could be advanced through the cauda equina without any resistance and injury of the normal structures in all cadavers. The manipulation of the tip of the endoscope was good enough to advance the endoscope to the desired direction and to observe fully around the area of interest in the lumbar region. In clinical applications, the endoscope could be used in all area in the lumbar region. The quality of the images obtained by the 2.2-mm endoscope were clear enough to detect cauda equina but not clear enough to detect filum terminale. In clinical application, we think to remove neurinoma of cauda equina will be possible with using 2.2mm endoscope in lumbar puncture method. However, when the filum terminale should be detected, using 2.2mm endoscope in lumbar puncture method is not recommended unless the quality of the images will be improved.

In the upper lumbar region, the endoscope could detect the anterior and posterior nerve roots exit from the spinal canal. Three routes were available for advancing the endoscope in the thoracic region; ventral route, lateral route, and dorsal route (Fig. 2). Three cadavers were applied for each route. In six cadavers which endoscope was advanced in lateral (three cadavers) and dorsal route (three cadavers), the endoscope could be advanced to the upper thoracic region without any resistance under endoscopic view. And after the endoscope was advanced to the upper thoracic region, macroscopic and microscopic examination of the spinal cord demonstrated that no injuries, including compression marks or trace of cord damage, were observed on the surface of the spinal cord. Although in the microscopic examination, the damage to the nerves could not be examined fully, macroscopic examination revealed there were no injuries, including compression marks or trace of nerve damage. For spinal cords of cadaver's being firm from formalin fixation, this result indicated that endoscope could be advanced safely not only in dorsal route, but also in lateral portion in the thoracic region even in cadavers. In living human, the spinal cord has mobility: thoracic spinal cord moves anteriorly in prone position, and the mobility ranging slightly over 2mm, occasionally exceed 4.5mm [19]. The mobility of thoracic spinal cord and the results of this study indicate that the endoscope can be advanced safely in dorsal route when the patient is put in prone position. Because there is little available information of the mobility of spinal cord in lateral position, we infer that in applying the endoscope in lateral route, to put the patients in lateral position, which is opposite to the legion side, will reduce the risk of the damage to the spinal cord. We think legions located in lateral or dorsal part of the spinal canal (for example spinal neurinoma, and arachnoid cyst that usually located in the posterior or posterolateral aspect of the spinal canal [26].) will be treated by endoscopic interventions through lumbar puncture.

In three cadavers that the endoscope was advanced in ventral route, the endoscope could not be advanced rostrally. Anatomically, it is known (1) the subarachnoid space in the thoracic region is smaller than that in the cervical and lumbo-sacral region. (2) the thoracic spine has kyphosis physiologically, which makes the ventral side of the subarachnoid space smaller than that of the dorsal side [19]. As mentioned above, the distance in the thoracic region is 1-3mm ventrally, dorsally 2-6mm. These anatomical traits and the spinal cord firmly fixed by formalin prevented the endoscope from being advanced in the ventral side in the thoracic region.

There are a few reports of successful treatment of arachnoid cyst in the ventral thoracic region with using spinal endoscope (not published). We think this procedure could be performed due to the mobility of the spinal cord and/or enough ventral subarachnoid space. In clinical cases, the ventral route will be applied to treat neuroentric cyst that usually located anterior or anterolateral aspect of spinal cord [25] and arachnoid cyst. However, advancing the endoscope in ventral route is more hazardous than in dorsal and lateral routes and more careful attention should be paid. Preoperative evaluation of not only the size of the subarachnoid space but also, in some cases that the subarachnoid space in the ventral side is less than 2.2mm, the mobility of the thoracic and lumbar spinal cord is necessary. And also, in advancing the endoscope in ventral route, to put the patient not in the prone position but in the lateral position will reduce the damage to spinal cord.

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