Method of Decompression by durotomy and duroplasty for cervical spinal cord injury in patients without fracture or dislocation

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KEYWORDS
spinal cord injury; spinal cord compartment syndrome; decompression; durotomy; spinal cord intramedullary hypertension.

ABSTRACT
Introduction: We developed the method of cervical spinal cord decompression through durotomy followed by duroplasty and analyzed its efficacy.
Purpose: To develop a tactic of decompression durotomy and duroplasty for the treatment of severe spinal cord injury (SCI) with extensive edema of the spinal cord and without intramedullary hematoma, and to demonstrate the effectiveness of this method.
Methods: From October 2016 to January 2018, 17 decompression operations were performed in the cervical spine in patients with SCI. Decompression laminectomy was done without durotomy in the first group of patients. In the second group, duroplasty of the spinal cord was performed after decompression durotomy. A total of 17 patients, 16 males (94%) and 1 female (6%), were operated on (ages from 32 to 66 years). The patients were divided into two groups: a control group and an experimental group. We used the ASIA scale for assessing the patients. The mean follow up time is 12 months (8–24 months).
Results: The first group, i.e., the control group consisted of 10 patients who underwent decompression laminectomy without durotomy. The second group, i.e., the experimental group consisted of 7 patients who underwent durotomy followed by duroplasty. In this group, the positive dynamics were observed in 6 patients. Out of 2 patients with ASIA grade “A”, one showed improvement to ASIA grade “C”, and one improved to ASIA “D”. Two patients with ASIA grade “B” showed recovery to ASIA “D”. Two patients with ASIA grade “C” improved to grade “D” while one patient showed no change from ASIA “C”. Durotomy and duroplasty was effective in the experimental group.
Conclusion: The performance of durotomy and duroplasty is an efficient method for the full-scale decompression of the spinal cord and the prevention of edema. This method aims at decreasing intraspinal pressure, as well as preventing ischemia and apoptosis, which is possible for the prevention and treatment of the spinal cord compartment syndrome or spinal cord intramedullary hypertension.

1 Introduction
The incidence of SCI without fracture and dislocation is the highest among the adult patients with cervical SCI [1]. Most of these patients have underlying cervical diseases such as cervical spondylosis and cervical...
stenosis [2]. Usually a mild violence leads to a cervical hyperextension injury in which the cervical spinal cord is compressed by the anterior intervertebral disc or the posterior ligamentum flavum leading to spinal cord injury [3]. The treatment of such diseases is controversial in clinical practice. Some scholars believe that such patients do not have obvious cervical fracture and dislocation, and conservative treatment of spinal cord function can be restored [4]. However, more ideas now support surgical treatment and many studies have proven that surgical treatment can achieve a better prognosis of neurological function [5, 6]. Now the discussion is more about the method and timing of the surgery [7, 8]. The purpose of the operation is to expand the volume of the spinal canal and relieve the compression of the spinal cord. The goal for treatment in acute SCI is to reduce the extent of secondary damage and facilitate neurological regeneration and functional recovery [9].

There is no denying that anterior resection of a herniated disc or posterior dilation of the spinal canal or resection of the lamina can relieve some of the compression of the spinal cord, but for extensive edema of the spinal cord, decompression of the disc and bone may not be sufficient [10, 11]. The increase in spinal cord pressure from SCI is not only caused by the compression of the bone and disc outside the spinal cord, but also by the restriction of the spinal dura mater and the swelling of the spinal cord itself. Spinal meninges may contribute to additional spinal cord compression via constrictive forces. The post-traumatic swelling of the spinal cord is worsened by additional dural constriction. In humans with SCI, compression may not only be extrinsic, but the spinal cord may be compressed against the dura due to intrinsic swelling. So in acute spinal cord injury, the spinal meninges especially dura mater play an important role in the increase of spinal cord pressure [12]. Durotomy decreases intracranial pressure (ICP) and limits perifocal edema and ischemia in the area of the spinal cord injury. Recent studies provide some evidence that Intraspinal Pressure (ISP) measurements and durotomy may be beneficial for individuals suffering from SCI. Compression of the spinal cord against the meninges in SCI patients causes a “compartment-like” syndrome [13]. With the occurrence of acute spinal cord injury, extensive edema of the spinal cord increases the intramedullary pressure. The limitation of the spinal canal and dura resulted in increased extramedullary pressure and simultaneous spinal cord internal and external compression lead to a narrow adhesion of the compartments, decreased cavity volume, blockage of cerebrospinal fluid, and arteriovenous obstruction resulting in ischemia, hypoxia and secondary injury. Qu et al. named these symptoms “Spinal Cord Compartment Syndrome” (SCCS) [14]. Just like intracranial hypertension after traumatic brain injury (TBI), this compartment syndrome can also be called as “spinal cord intramedullary hypertension (SCImH)”. Since the ultimate goal of such surgery is decompression, we believe that the decompression of the spinal cord should be more adequate. Perhaps in addition to laminectomy and discectomy, durotomy and duraplasty are necessary.

2 Methods

Between October 2016 and January 2018, we performed 17 decompression surgeries for cervical SCI without fracture or dislocation in the Sino-Canada spinal and spinal cord center of Wuhan Union Hospital. A total of 17 patients, 16 males (94%) and 1 female (6%) were operated on (ages from 32 to 66 years). 11 cases of the patients fell from a height, 2 patients were involved in traffic accidents, while 4 patients had some other form of injury. MRI showed that all those patients have edema of spinal cord but without intramedullary hematoma. Surgeries were performed within 3 days of injury. The patients were divided into two groups. The first group consisted of 10 patients, 10 (100%) males submitted to the decompression laminectomy without durotomy. The second group consisted of 7 patients, 6 (86%) males and 1 (14%) female who underwent decompression durotomy followed by duroplasty.

The severity of the neurological impairment was based according to American Spinal Injury Association (ASIA) scale. In the first group, there was 1 patient graded as ASIA grade “A”, four patients graded as ASIA “B” and five patients graded as ASIA “C”. In the second group, two patients were graded as ASIA grade “A” while two patients were graded as ASIA grade “B”, and three graded as ASIA “C”. The ASIA
scale was used for neurological examination to carry out efficacy control.

While being placed in a prone position, laminectomy was performed in routine procedure and standards in the patients of group 1. The bone fragments were removed, muscles on both sides of the spinous process were dissected and lamina was removed, after which reclusion of bone and fusion of the spine was performed for stabilization.

We finished durotomy and duroplasty in group 2 along the entire length of the laminectomy. The dura was longitudinally incised under a surgical microscope. Nerve hooks were used in the process. The spinal cord was observed and the cerebrospinal fluid circulation was restored (Fig. 1). A dural graft was cut out and was then sutured with the dura (Fig. 2). Some hemorrhage and edema were observed after cutting of the dura mater so some space was left reserved to aid microcirculation and set bounds to the secondary damage of the medullary substance.

Two weeks after the operation, the X-ray, CT scan and MR plain scan of the injured spine were reviewed. The assessments before and after the patient's surgery were performed by the same physician.

![Fig. 1](image1.png)  **Fig. 1**  The spinal cord can be observed after incision of the dura.

![Fig. 2](image2.png)  **Fig. 2**  The dural patch sutured with the dura after duroplasty.

### 3 Results

We used the ASIA scale for assessing the efficacy. In this control group, the improvement was observed in 7 out of the 10 patients. One patient with ASIA grade “A” improved to grade “B”. Out of four patients with ASIA grade “B”, two patients showed recovery to ASIA “C”, and one recovered to ASIA “D”, while one patient had no change from grade “B”. For three patients with ASIA grade “C”, there was no change in the grade. Two patients with ASIA grade “C” showed improvement to ASIA grade “D”. The second group consisted of 7 patients who underwent durotomy followed by duroplasty. In this group, the positive dynamics were observed in 6 patients. Out of 2 patients rated as ASIA grade “A”, one showed improvement to grade “C”, and one improved to grade “D”. Two patients with ASIA grade “B” showed recovery to ASIA grade “D”. Two patients with grade “C” improved to grade “D” while one patient showed no change from ASIA “C”. Table 1 shows the changes in ASIA grade of the patients in both groups.
Table 1  Changes of ASIA grade after surgery (A-A, B-B, C-C, D-D—0; A-B, B-C, C-D—1; A-C, B-D—2; A-D, B-E—3).

<table>
<thead>
<tr>
<th>Method of decompression</th>
<th>ASIA grade before operation</th>
<th>ASIA grade after operation</th>
<th>Improvement of ASIA grade</th>
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<tr>
<td>Laminectomy</td>
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<td>Durotomy</td>
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One patient from this study, male, 49 years old was admitted with cervical SCI from C4—C7 with paraplegia. The patient underwent cervical posterior decompression by durotomy and duroplasty after his spinal cord injury. Figures 3A and 3B show imaging of the SCI at the time of admission before surgery was performed. Figure 3C shows the view during surgery before durotomy and duroplasty were performed. Lastly, Fig. 3D shows the microscopic view of the spinal cord after the incision of the dura. Figure 3E shows the duroplasty after durotomy. Figures 3F, 3G, and 3H show imaging after surgery. The patient's change in ASIA grade was B to D.

Thus, duroplasty can be used effectively in decompression surgeries of the cervical spinal cord without fracture or dislocation. From the results of this patient and the other patients of group 2, it is proven that duroplasty is very beneficial.

4 Complications

Left pulmonary embolism was observed in one of the laminectomy group patients after surgery. After surgery, calcification of ligaments was seen in 2 patients and degeneration was seen in 1 patient. There was no occurrence of wound infection and hematoma after surgery in any of the patients. There was no observation of edema after duroplasty.

5 Discussion

For the treatment of SCI without fracture and dislocation in adults, surgical decompression has been recognized by most [5, 6]. Decompression is thought to help prevent further primary injury, as well as secondary injury from ischemia, vasospasm, edema, inflammation, free radicals, and apoptosis. In clinical observation, the results of surgery without fracture and dislocation of SCI are usually better than those with fracture and dislocation of spinal cord injury [15]. However, there are still some cases where neurological recovery is not ideal despite surgical treatment. There are some patients who do not have any recovery or may even have neurological deterioration. The reasons for this may be related to the extent and adequacy of spinal cord decompression in addition to the degree of spinal cord primary injury and the timing of surgery. Compared to SCI with fracture and dislocation, the reason that ISP may increase without fracture and dislocation is more likely to be edema of spinal cord itself and compression of dural, arachnoid and pia mater membrane.

Winestone’s research on humans demonstrates that posterior laminar decompression only reduced intramedullary pressure (IMP) by approximately 15%–25%. Laminectomy and durotomy resulted in an average reduction in IMP of approximately 60%–75%. Laminectomy with durotomy and pial opening resulted in an average reduction in IMP of approximately 89%–100%. In their study, the pia mater and dura mater, as well as the lamina, contributed significantly to the elevated spinal cord IMP in severe cervical and thoracic kyphotic deformities [16]. One study by Perkins reported 6 patients with SCI who underwent bony decompression with durotomy. Full neurological recovery occurred in three of the six neurologically impaired patients and partial recovery in the remaining three. It was of belief that bony decompression with laminectomy released the spinal epidural veins which had become congested and had inhibited the free flow of CSF, and dural decompression can be used in the prevention of high ISP [17]. Papadopoulos also
demonstrated that high ISP and low SCPP are associated with injury site ischaemia, which likely causes secondary damage [18]. In patients with extensive swelling from spinal cord injury, durotomy can relieve the blockage of spinal epidural veins and arterioles of the cord, as well as relieve secondary injury [19]. In a study by Christopher et al., it was proven that duroplasty improved CSF flow by limiting meningeal fibrosis and subarachnoid CSF blockage. This study showed that duroplasty reduces connective tissue scar formation by decreasing the deposition of two ECM molecules. In addition, duroplasty after SCI resulted in a reduction in the infiltration of activated macrophages within and surrounding the lesion associated with a nearly complete attenuation in post traumatic cystic cavitation [20]. Tomasz et al. conducted a study on extensive

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**Fig. 3** One case of duroplasty: A and B show the preoperative cervical CT and MRI; C, D and E show the intra-operative imaging; F, G and H show the postoperative imaging of this patient.
duroplasty and explained that the swollen spinal cord becomes compressed against the surrounding dura, which was associated with an increase of ISP. After tSCI, intrathecal hypertension can contribute to compression of the spinal veins and venous stasis. Epidural venous congestion may reduce the arteriovenous pressure gradient within the cord, decreasing tissue perfusion and promoting ischemia. From their trial, Phang et al. showed that the laminectomy plus duroplasty group had a greater increase in the anteroposterior diameter of the dural canal at the injury site and more effective decompression of the injured cord [21]. Qu et al. stated that due to the constraint imposed by the vertebral canal and dura, the increase in spinal cord cross section area decreases the volume of the epidural and subarachnoid spaces, blocking the epidural veins, arteriole of the cord, and cerebrospinal fluid (CSF) flow and inducing arachnoid adhesion. The lack of blood supply and CSF infusion exacerbate the spinal cord edema. Also, bony fragments may insert into the dura and spinal cord surface, and these should be removed. Similar to osteofascial compartment syndrome, SCI with edema is characterized by the “spinal cord compartment syndrome” which is described in detail by internal compression from spinal cord edema and external compression from the vertebral canal and dura blocking the spinal epidural veins, arteriole of the cord, and CSF flow, which aggravates the ischemia and hypoxia of injury site and secondary damage. The ischemia and hypoxia exacerbate the edema and increase the internal compression, forming a self-sustaining “vicious cycle” [14, 19]. Similar to the intracranial hypertension after traumatic brain injury, the SCCS can also be called “spinal cord intramedullary hypertension (SCImH)”.

Evidence has shown that osseous decompression and restoration of the spinal realignment may not be sufficient to improve “Spinal Cord Compartment Syndrome (SCCS)” or “spinal cord intramedullary hypertension (SCImH)”. Based on the durotomy surgeries performed by our team, it can be stated that durotomy and duraplasty is effective in decompression for relieving pressure on the injured spinal cord and is more efficient than decompression laminectomy alone. According to the results it can be confirmed that durotomy and duraplasty was very effective on the patients of group 2.

6 Limitations of this study

The sample size was small, and the follow-up time was short. The next study will include a larger sample size as well as an extended follow-up time. The majority of other patients with SCI had fracture or dislocation so could not be included in this study, thus reducing the sample size.

7 Conclusion

Our method of decompression laminectomy and durotomy is beneficial for the full-scale decompression of spinal cord and prevention of the extension of edema. It appeared to be an efficient method and can be done after laminectomy or laminoplasty following by possible enhanced efficacy of surgeries.

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Disclosure

The authors declare no conflict of interests for this paper.

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