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ULTRASOUND

Inadequate spinal cord expansion in intraoperative ultrasound after decompression may predict neurological recovery of degenerative cervical myelopathy

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Abstract

Objective To compare the neurological recovery between patients with adequate and inadequate immediate spinal cord expansion after sufficient decompression in degenerative cervical myelopathy (DCM).

Methods Twenty-seven patients subjected to French-door laminoplasty underwent the guidance of intraoperative ultrasound (IOUS) and were prospectively included. The modified Japanese Orthopedic Association (mJOA) score was evaluated before surgery and at 12 months postoperatively. The maximum spinal cord compression (MSCC) after sufficient decompression was calculated on the IOUS image; patients were divided into adequate (MSCC ≥ 0.95) and inadequate (MSCC < 0.95) expansion groups according to the MSCC. The mJOA score, spinal cord hyperechogenicity, age at surgery, symptom duration, occupational rate of the spinal canal, and the minimum anteroposterior diameter of the spinal cord between the two groups were compared.

Results Initially, 2 cases showed residual compression on IOUS; after further decompression, all patients acquired sufficient decompression. All patients achieved improvements in mJOA scores with an average recovery rate of 68.6 ± 20.3%. The recovery rate of the mJOA score of the inadequate expansion group was significantly inferior to that of the adequate expansion group (59.2 ± 21.7% versus 76.2 ± 16.2%, $p = 0.028$). The spinal cord hyperechogenicity was more common in the inadequate expansion group, while the spinal cord anteroposterior diameter of the inadequate expansion group was significantly smaller than that of the adequate expansion group.

Conclusions The application of IOUS in French-door laminoplasty could help to confirm sufficient decompression for the treatment of DCM. Inadequate spinal cord expansion after sufficient decompression had the high possibility of predicting less satisfactory neurological recovery of DCM.

Key Points

- *The intraoperative ultrasound revealed that not all degenerative cervical myelopathy patients acquired adequate spinal cord expansion after sufficient decompression.*
- *Patients who failed to acquire adequate spinal cord expansion commonly combined with spinal cord hyperechogenicity and trended to achieve less satisfactory neurological recovery after surgical decompression.*
- *Inadequate spinal cord expansion after sufficient decompression had the high possibility of predicting less satisfactory neurological recovery of patients with degenerative cervical myelopathy.*

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Keywords Cervical myelopathy · Decompression · Laminoplasty · Spinal cord compression

Abbreviations

APD	Anteroposterior diameter
DCM	Degenerative cervical myelopathy
IOUS	Intraoperative ultrasound
mJOA	Modified Japanese Orthopedic Association
RR	Recovery rate

Introduction

Degenerative cervical myelopathy (DCM) is widely considered as the most common non-traumatic spinal cord disorder, leading to neurological dysfunction in adults [1]. It mainly includes cervical spondylotic myelopathy, cervical ossification of the posterior longitudinal ligament, and congenital spinal stenosis among others [2]. The chronic mechanical compression applied to the spinal cord, resulting from the cervical degenerative processes, caused direct impairment to the spinal cord and triggered a cascade of pathological processes that aggravated the neurological injury [3]. Studies about the natural history of DCM demonstrated that a substantial number of patients experienced a progressive, stepwise decline in spinal cord function [4]. Surgical decompression, which could alleviate mechanical compression on the spinal cord, has been suggested as an effective strategy for DCM [5]. Accumulated evidence revealed that surgical decompression prevented further deterioration and improved neurological recovery for the majority of DCM patients [6, 7]. However, unsatisfactory neurological improvement could be observed in some patients who reported relapse or continued to deteriorate after decompression [8]. Multiple studies have been conducted to investigate the factors associated with unsatisfactory surgical outcomes to elucidate this phenomenon. Symptom duration, age at surgery, compression, and decompression status were confirmed to contribute differently in predicting surgical outcomes, though the prognostic utility of any of the above parameters is still controversial [9–13]. For these parameters, surgical intervention could directly alter the decompression status only. To acquire sufficient decompression, intraoperative ultrasound (IOUS) was performed to evaluate and guide the decompression and achieved more satisfactory surgical outcomes [14, 15]. Interestingly, metrics of spinal cord reflected on IOUS were also considered as potential prognosis indicators for DCM [16, 17]. Studies on the correlation between neurological function and immediate expansion of the spinal cord after sufficient decompression were still scantly. In order to determine a new predictor of neurological recovery after surgical treatment for degenerative cervical myelopathy (DCM), we designed this study, in which the patients were divided into adequate and inadequate expansion groups according to the immediate expansion of the spinal cord after sufficient decompression assessed by IOUS, and the postoperative neurological recovery and the associated factors between the two groups were compared. We hypothesized that inadequate spinal cord expansion after sufficient decompression had the high possibility to predict less satisfactory neurological recovery of patients with DCM.

Materials and methods

Study population

The study protocol was approved by the Institutional Review Board of the study hospital. Signed informed consent was obtained from all participants of the study. A previous study has confirmed that laminoplasty was the better choice for the multilevel DCM (≥ 3) instead of anterior surgery [18], and French-door laminoplasty could provide sufficient space for the application of IOUS [15, 17]. A total of 32 consecutive patients with multilevel DCM were prospectively enrolled between October 2018 and August 2019. Patients with a history of other spinal disorders, neurological injury, infection, tumor, and rheumatoid arthritis were excluded. Finally, 27 patients (20 males and 7 females) who had been followed for 12 months were included in this study. The mean age at these patients' surgery was 56.8 ± 11.6 years, and the average symptom duration was 43.5 ± 39.0 months (Table 1).

Surgical techniques

All patients received French-door laminoplasty from the same group of surgeons, performed according to Kurokawa's method with a few modifications [19]. After the bilateral paravertebral muscles from the spinous processes were detached, the centers of spinous processes were cut using a fretsaw. Bilateral gutters were created as hinges at the border of the laminae and facets. After the halves of the laminae were elevated and fixed to the bilateral skin provisionally, normal saline was infused to form an acoustic window, then a linear array transducer of IOUS (M9Expert, Mindray Medical International Limited) was used to observe the spinal cord and record the images and videos. If residual compression was observed, further decompression under IOUS guidance was done. After observation, the appropriately sized hydroxyapatite spacers were tied in place to bridge the bilateral edges of the laminae and were fixed with wires. Finally, a drainage tube was placed, and the wound was closed in layers (Fig. 1).

Table 1 The demographic data of the patients

Indicator	Result
Number of cases	27
Gender (male/female)	20/7
Age at surgery (years)	56.8 ± 11.6
Symptom duration (months)	43.5 ± 39.0

Neurofunctional evaluations

Neurological function was evaluated using the modified Japanese Orthopedic Association (mJOA) score before surgery and at 12 months postoperatively. The recovery rate (RR) of the mJOA score was calculated using the previously described formula [20]: *RR of mJOA score = (postoperative mJOA score − preoperative mJOA score)/(17 − preoperative mJOA score) × 100%.*

Radiological assessments

The presence of cervical laminas before decompression or postoperative hydroxyapatite spacer could block the ultrasonic waves, leading to difficulties in evaluating the spinal cord by IOUS before decompression and in postoperative follow-up. So only the intraoperative assessment by ultrasound was conducted. The videos of spinal cord movement after decompression recorded by IOUS were used to assess the decompression status. The midsagittal IOUS image of the spinal cord (the midsagittal slice was determined by visualization of the spinal cord central echo complex) was selected to assess the expansion and echogenicity after decompression.

In brief, the videos of each patient contained at least 3 pulsation periods of the spinal cord in longitudinal views recorded by IOUS and were used to assess the decompression status. The positional relation between the anterior border of the spinal cord and the compression elements was judged and then classified into three types as described previously [15, 17]: type 1 (non-contact)—the spinal cord invariably separated from the anterior compression; the spinal cord completely floated in the cerebrospinal fluid (Fig. 2a, Video 1); type 2 (contact and apart)—the spinal cord occasionally touched anterior elements but lifted off as synchronized with the spinal cord pulsation (Fig. 2b, c, Video 2); and type 3 (contact)—the spinal cord contacted with the anterior structures continuously; the cerebrospinal fluid space ventral to the spinal cord was not obtained at the compression level (Fig. 2d, Video 3). Type 1 and 2 were sufficient decompression, while type 3 was considered as insufficient decompression [15, 17].

After decompression, the maximum spinal cord compression (MSCC) derived from IOUS was measured and calculated referring to the MRI measurement described previously [22]. Briefly, the anteroposterior diameter (APD) at the maximum compression level and the compression-free level was measured and recorded as $APD_{compression}$ and APD_{free} respectively, then the MSCC was calculated with the formula $MSCC = APD_{compression}/APD_{free}$. The immediate expansion of the spinal cord was classified into two categories based on the MSCC: adequate, the MSCC ≥ 0.95, and inadequate, the MSCC < 0.95 (Fig. 3).

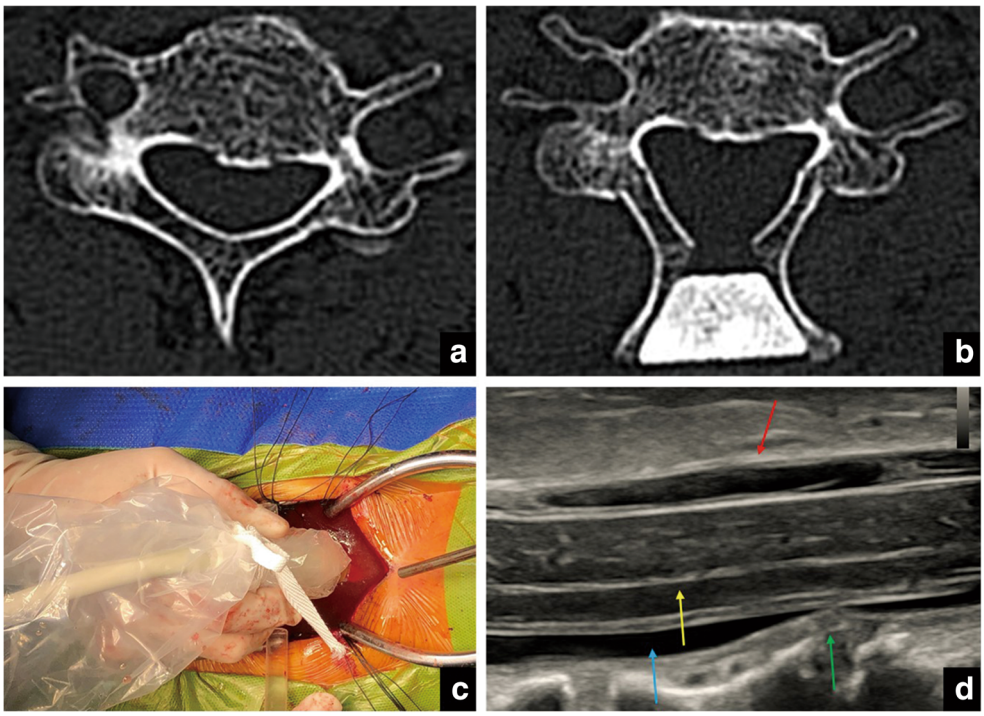

Fig. 1 The diagram of French-door laminoplasty and the application of intraoperative ultrasound. **a** The preoperative transverse CT image of the cervical spine; **b** the transverse CT image of the cervical spine after French-door laminoplasty (**c**), the application of intraoperative ultrasound. **d** The anatomical structures based on intraoperative ultrasound; red arrow indicates the spinal dura mater, yellow arrows indicate the spinal cord central echo complex, the blue arrow indicates the subarachnoid space and the green arrow indicates the cervical disc

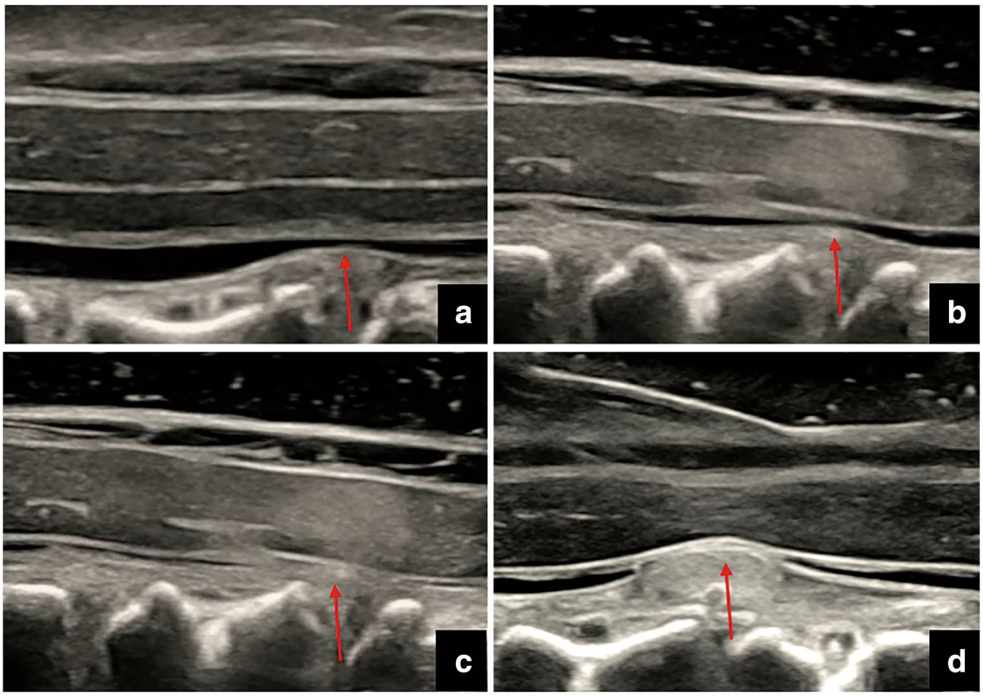

Fig. 2 The diagram of the decompression status based on intraoperative ultrasound. **a** Illustration of type 1 (non-contact) decompression, the spinal cord invariably separated from the anterior compression, the spinal cord completely floated in the cerebrospinal fluid; **b**, **c** illustration of the type 2 (contact and apart) decompression, the spinal cord occasionally touched anterior elements but lifted off as synchronized with the spinal cord pulsation; **d** illustration of the type 3 (contact) decompression, the spinal cord contacted with the anterior structures continuously, the cerebrospinal fluid space ventral to the spinal cord was not obtained at the compression level. The red arrows indicate the maximum compression level

The echogenicity of the spinal cord was also classified into iso-echoic, and hyperechogenicity referred to the method of the classification of T2W MRI signal intensity [16, 23]. Iso-echoic, the brightness of the spinal cord at the compression level was similar to that at the compression-free level (Fig. 4a); hyperechogenicity, the brightness of the spinal cord at the compression level, was higher than that at the compression-free level (Fig. 4b).

The MRI was done in all patients before surgery and at 12 months postoperatively. The spinal canal's occupational rate and APD of the spinal cord at the maximum compressive level were measured on preoperative transverse plane T2W MRI (Fig. 5a, b). And the MSCC was measured on postoperative midsagittal T2W MRI with a similar method as IOUS (Fig. 5c).

All patients' images and videos were assessed independently by the same two researchers who did not participate in the neurological assessments, and assessments were repeated three times using the mean for statistical analysis.

Statistical analysis

Data were analyzed using SPSS 24.0 statistical software. All values were expressed as mean ± standard deviation. The paired *t* test was used to compare pre- and post-operative mJOA scores for all patients. The mJOA score, the RR of the mJOA score, age at surgery, symptom duration, occupational rate of the spinal canal, and minimum APD of the spinal cord between different groups were compared with an unpaired *t* test; the displaying rate of hyperechogenicity between different groups was compared with the chi-square test; and the correlation between IOUS MSCC and MRI MSCC was analyzed by Spearman correlation analysis. p values < 0.05 were considered statistically significant.

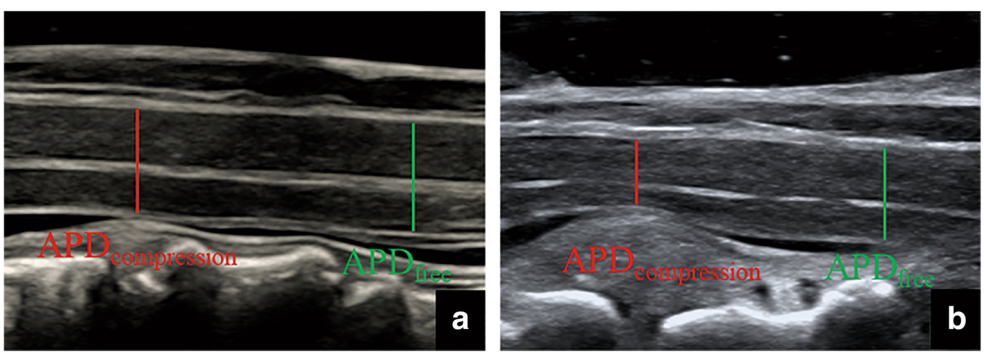

Fig. 3 The diagram of the measurement of the anteroposterior diameter (APD) of the spinal cord on intraoperative ultrasound. **a** The case in the adequate expansion group; **b** the case in the inadequate expansion group. $APD_{compression}$ indicates the APD of maximum compression level, APD_{free} indicates the APD of compression-fee level

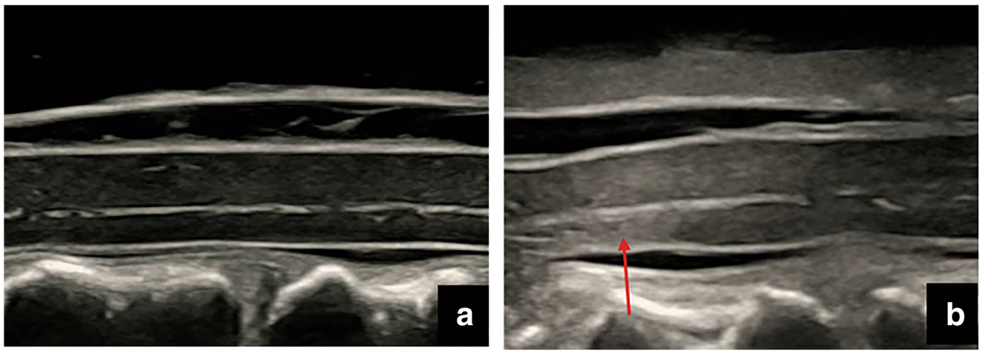

Fig. 4 The diagram of the spinal cord echogenicity. **a** The illustration of the spinal cord with iso-echoic; **b** the illustration of a spinal cord with hyperechogenicity; the red arrow indicates hyperechogenicity

Results

No complications were observed until the latest follow-up. The average mJOA score of all patients improved significantly from 11.7 ± 2.5 before surgery to 15.3 ± 1.3 at 12 months after surgery ($p < 0.001$), and the average RR of the mJOA score was 68.6 ± 20.3%.

For decompression status, 13 patients were classified as type 1, 12 patients were classified as type 2, and 2 patients was considered as type 3 initially. After further decompression, two type 3 cases converted to type 2 (Fig. 6). Finally, 13 patients were classified as type 1, 14 patients were classified as type 2, and no type 3 patient existed; all patients acquired sufficient decompression. The differences between pre- and post-operative mJOA scores and the RR of the mJOA score between type 1 and type 2 patients were not significant (Table 2).

For the spinal cord expansion, adequate spinal cord expansion was achieved in 15 individuals, while 12 patients failed to acquire adequate expansion. For patients with adequate expansion, the average mJOA score improved significantly from 11.4 ± 2.8 preoperatively to 15.7 ± 0.9 at 12 months postoperatively ($p < 0.001$) with an average RR of 76.2 ± 16.2%. For patients with inadequate expansion, the average mJOA score improved significantly from 12.0 ± 2.1 preoperatively to 14.9 ± 1.7 at 12 months postoperatively ($p < 0.001$) with an average RR of 59.2 ± 21.7%. The RR of the mJOA score of the inadequate group was significantly inferior to that of the adequate group ($p = 0.028$). The differences between pre- and post-operative mJOA scores on adequate and inadequate expansion groups were not significant ($p > 0.05$).

For echogenicity of the spinal cord, 21 cases were categorized into hyperechogenicity; the remaining 6 patients were considered as iso-echo. The differences of pre- and post-operative mJOA scores and the RR of mJOA scores between hyperechogenicity and iso-echo patients were not significant. The displaying rate of hyperechogenicity in the inadequate expansion group (12/12, 100.0%) was significantly higher than that of the adequate expansion group (9/15, 60.0%), $p = 0.020$ (Table 3).

The above results indicated that the spinal cord expansion correlated with the mJOA score significantly. Preliminarily exploring the factors that might affect the spinal cord expansion, the age at surgery, symptom duration, occupational rate of the spinal canal, and minimum APD of the spinal cord were compared between the adequate and inadequate expansion groups. The differences in age at surgery, symptom duration, and occupational rate of the spinal canal between the two groups were not

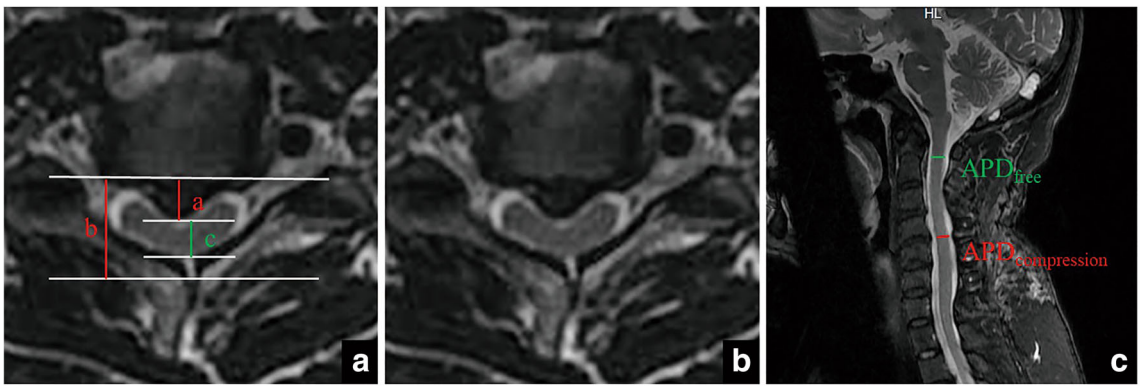

Fig. 5 The diagram of measurements on T2W MRI. **a** The illustration of measurements on preoperative T2W MRI; the occupational rate of the spinal canal was calculated by *a*/*b*; c indicated the anteroposterior diameter of the spinal cord; **b** the original image of ***a*** without marks; **c** the illustration of measurements on postoperative T2W MRI, the $APD_{compression}$ indicates the anteroposterior diameter (APD) of maximum compression level, APD_{free} indicates the APD of compression-free level

Table 2 The mJOA score of different groups

Indicator	Sample	Preoperative	Postoperative	Recovery rate (%)
All patients	27	11.7 ± 2.5	15.3 ± 1.3*	68.6 ± 20.3
Decompression				
Type 1	13	12.0 ± 2.5	15.2 ± 1.7*	66.3 ± 21.8
Type 2	14	11.4 ± 2.5	15.5 ± 1.0*	70.8 ± 19.4
Expansion				
Adequate	15	11.4 ± 2.8	15.7 ± 0.9*	76.2 ± 16.2**
Inadequate	12	12.0 ± 2.1	14.9 ± 1.7*	59.2 ± 21.7
Echogenicity				
Hyperechogenicity	21	11.2 ± 2.5	15.1 ± 1.4*	66.4 ± 21.7
Iso-echo	6	13.4 ± 1.5	16.1 ± 0.7*	76.3 ± 13.0

The mJOA score indicates the modified Japanese Orthopedic Association score

* Compared with preoperative, $p < 0.05$; ** compared with the inadequate expansion group, $p < 0.05$

significant; the mean APD of the spinal cord in the inadequate expansion group was significantly smaller than that of the adequate expansion group (4.4 ± 0.8 mm versus 5.4 ± 1.1 mm, $p = 0.015$) (Table 4).

For the MRI at 12 months after surgery, the cerebrospinal fluid space ventral to the spinal cord was observed in all patients. Expect for one patient in the inadequate group, the MRI MSCC of all patients was more than 0.95. The difference of MRI MSCC between the adequate and inadequate groups was not significant. There was no significant correlation between IOUS MSCC and MRI MSCC ($p > 0.05$).

Discussion

In this study, the decompression status and immediate expansion of the spinal cord after decompression were evaluated by IOUS in the surgery of DCM. The results revealed that compared with the adequate spinal cord expansion, patients who acquired inadequate spinal cord expansion after sufficient decompression achieved less satisfactory neurological recovery, and patients with inadequate spinal cord expansion were more commonly combining with spinal cord hyperechogenicity.

To achieve satisfactory neurological recovery of DCM is commonly research focus. Surgical decompression is a highly effective method for DCM regardless of the severity of neurological deficits [6, 7, 24]. The majority of patients acquired

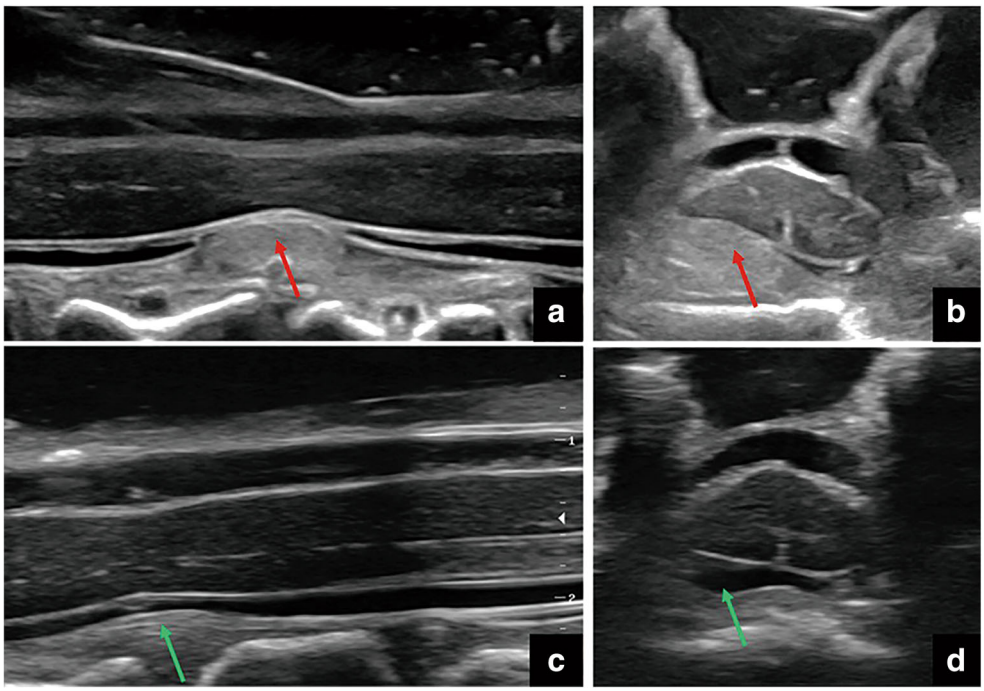

Fig. 6 Representative case of the converting from type 3 to type 2 decompression based on intraoperative ultrasound (IOUS). **a**, **b** the IOUS images of the spinal cord before further decompression; **c**, **d** the IOUS images of the spinal cord after further decompression. In this case, after French-door laminoplasty, the IOUS was used to evaluate the decompression (**a**, **b**). The unilateral herniated disc (red arrows) which compressed the spinal cord was visualized at the C5-6, then further decompression under IOUS guidance was performed, the herniated disc was removed posteriorly (green arrows). Finally, the decompression was converted from type 3 to type 2 (**c**, **d**)

Table 3 The comparison of spinal cord hyperechogenicity between adequate and inadequate expansion groups

	Adequate expansion	Inadequate expansion	Total
Iso-echo	6	0	6
Hyperechogenicity	9	12	21
Displaying rate of hyperechogenicity (%)	60.0	100.0*	77.78

* Compared with that of adequate expansion, $p < 0.05$

satisfactory outcomes by surgical decompression, but many preoperative and surgical factors could affect the effectiveness of surgical outcomes [25]. Hence, studies focusing on the modifications of decompression and the predicting of postoperative recovery were conducted. Previous studies indicated that the alleviation of spinal cord compression derived from the decompression is the crucial tenet of operative management for DCM [2, 26]. Therefore, IOUS, which could reveal the anatomical relationship between the spinal cord and its anterior structures in real time, was used to guide posterior decompression in DCM [14]. In this study, all cases acquired sufficient decompression according to the previous classification method [21], and the pre- and post-operative mJOA scores and the RR of the mJOA score between type 1 and type 2 decompression showed no significant difference. Spinal cord expansion could occur after decompression; recent studies have shown that the postoperative enlargement of the spinal cord correlated with neurological improvement significantly [27, 28]. The inadequate immediate expansion of the spinal cord after decompression was observed in 12 individuals, and the RR of the mJOA score for those patients was significantly inferior to that of the remaining 15 patients with adequate spinal cord expansion in this study. Based on this observation, we speculated that the immediate inadequate spinal cord expansion after sufficient decompression evaluated by IOUS was a potential risk factor for DCM recovery.

For patients with inadequate spinal cord expansion, hyperechogenicity was observed in all cases without exception. In this study, the pre- and post-operative mJOA score and the RR of the mJOA score in patients with hyperechogenicity were inferior to those of the iso-echo, but without statistically significant difference which might be due to the small sample size of this study. According to the ultrasonography principles, differences in the density of adjacent tissues result in different echoes and are reflected as different gray values on ultrasound images [29]. The hyperechogenicity of the spinal cord at the compression level indicated a significant difference in spinal cord density [16]. However, the critical cause of DCM was the chronic compression subjected to the static and dynamic mechanical forces acting on the spinal cord [30]. Because of the chronic compression, it will be loss of neurocytes, proliferative fibroblasts, and capillary endothelial cells; fibrin deposition; and even fibrosis that will occur in the compression region, which will lead to the uneven density of the spinal cord [2, 31, 32] and finally be reflected as hyperechogenicity on IOUS. On the one hand, these pathological alterations were signs of spinal cord impairment; on the other hand, the uneven density secondary to these pathological alterations might reduce elasticity and restrict the spinal cord expansion. The inadequate spinal cord expansion is always accompanied by hyperechogenicity, but the hyperechogenicity could be observed in both adequate and inadequate spinal cord expansion. It might suggest that the uneven density progress to restrict the expansion of the spinal cord is a more significant risk factor than the appearance of hyperechogenicity alone. The inadequate expansion and the hyperechogenicity assessed by IOUS were the manifestations of spinal cord impairment; inadequate expansion combined with hyperechogenicity might indicate more serious impairment. For cases with inadequate expansion, it is difficult to discriminate from spinal cord atrophy by ultrasonic images. Ultrasonic elastography is widely used in the diagnosis of thyroid tumors [33]; it may be also useful in identifying whether the spinal cord was atrophied, but further exploration is needed. Recently, some surgeons conducted epidural and intradural decompression for DCM patients, which was believed to be helpful in separating arachnoid adhesion, restoring cerebrospinal fluid flow, and increasing spinal blood flow [34]. Further studies are needed to estimate the outcomes of these surgical approaches.

Table 4 The clinical and radiological indicators of different classifications based on spinal cord expansion

Indicator	Age at surgery (years)	Symptom duration (months)	Occupational rate (%)	Minimum APD (mm)
Adequate expansion	54.2 ± 13.9	43.9 ± 39.0	28.9 ± 10.0	5.4 ± 1.1
Inadequate expansion	59.8 ± 7.5	43.0 ± 40.7	30.0 ± 7.0	4.4 ± 0.8*

APD indicates anteroposterior diameter; *compared with that of adequate expansion, $p < 0.05$

Factors that might influence the expansion of the spinal cord were also worth a mention. Age at surgery, duration of symptom, occupational rate of the spinal canal, and minimum APD of the spinal cord were divided into two groups based on the expansion status of the spinal cord and then compared respectively according to the expansion status of the spinal cord. The minimum APD of the spinal cord in the inadequate expansion group was significantly inferior to that of the adequate expansion group. The smaller APD of the spinal cord indicated more severe compression, and the chronic severe compression might lead to severe pathological alterations [22]. Previous studies suggested that age over 60 years at the time of surgery was a risk factor for poor prognosis [35], but the patients included in this study were relatively young, which might contribute to no significant difference in age at surgery between the two groups in our study. Symptom duration was a highly subjective indicator, and reliability was relatively low. Besides, the axial symptoms commonly occurred before the symptoms of myelopathy; it might influence this indicator's accuracy. Moreover, the variability in the natural history between DCM patients may also make contributions. Many patients experience stepwise progressive deterioration of symptoms over time, others exhibited periods of quiescence or slight improvement, and some patients confronted by rapid progression of neurological impairment [36, 37]. For the occupational rate of the spinal canal, the APD of the spinal canal included the thickness of the ligamentum flavum; ligamentum flavum hypertrophy not only reduced the actual volume of the spinal canal but also led to spinal cord compression. Additionally, the postoperative expansion of spinal cord was assessed by MRI at 12 months after surgery, which showed that the average expansion of the spinal cord was larger than that measured by IOUS. It might mainly be attributed to the different observation timing. A previous study also revealed that the spinal cord could still expand gradually after the immediate expansion after decompression [21]. Postoperative MRI may be helpful to distinguish spinal cord atrophy and prolonged inadequate expansion.

This study has the following limitations: as an exploratory study, the sample size was small; with the mJOA score as the only neurological indicator, subjectivity may lead to bias of results; some parameters (hyperechogenicity and expansion status of the spinal cord) used in comparisons were not quantified. Based on this study's findings, future studies with large samples, long-term follow-up, and quantitative assessments derived from IOUS integrated with an objective evaluation such as the electrophysiologic evaluation should be conducted. Multivariate analysis is necessary to further analyze the correlations between spinal cord expansion and the potential risk factors. Due to spinal cord biopsy infeasibility, animal experiments may elucidate the structural correlates of IOUS metrics of DCM. Another limitation for IOUS is that it can be applied in dorsal surgery only.

Conclusions

The application of IOUS in French-door laminoplasty could help to confirm sufficient surgical decompression for treatment of DCM. Inadequate spinal cord expansion despite sufficient decompression was associated with less satisfactory neurological recovery of DCM patients.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00330-021-08000-x.

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Declarations

Guarantor The scientific guarantor of this publication is Shaoyu Liu, The Seventh Affiliated Hospital, Sun Yat-sen University.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry One of the authors has significant statistical expertise. No complex statistical methods were necessary for this paper.

Informed consent *Only if the study is on human subjects:*
Written informed consent was obtained from all subjects (patients) in this study.

Ethical approval Institutional Review Board approval was obtained.
The Seventh Affiliated Hospital of Sun Yat-sen University Ethics Committee.

Study subjects or cohorts overlap Some study subjects or cohorts have been previously reported in "Chen G, Li J, Wei F, Ji Q, Sui W, Chen B, Zou X, Xu Z, Liu X, Liu S. Short-term predictive potential of quantitative assessment of spinal cord impairment in patients undergoing French-door laminoplasty for degenerative cervical myelopathy: preliminary results of an exploratory study exploiting intraoperative ultrasound data. BMC Musculoskelet Disord. 2020 May 30;21(1):336. doi: 10.1186/s12891-020-03319-w. PMID: 32473626; PMCID: PMC7261379.
No overlaps.

Methodology
- prospective
- diagnostic or prognostic study
- performed at one institution

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