CLINICAL ARTICLE

Correlation Analysis for Selection of Microtitanium Plates with Different Specifications for Use in a Cervical Vertebral Dome Expansion Laminoplasty

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Objective: To analyze correlations between the selection of microtitanium plates with different specifications for use in a cervical vertebral dome expansion laminoplasty.

Methods: Sixteen patients that underwent the cervical vertebral dome expansion laminoplasty with a cervical spinal stenosis angioplasty procedure for treatment of their cervical spinal cords were recruited at our hospital. From February 2017 to September 2018, medical records confirmed that all patients underwent cervical CT and MRI tests pre- and postsurgery. The anteroposterior diameter of the spinal canal, changes in the cross-sectional area of the spinal canal, and the pre- and postsurgery distance of the cervical spinal cord after applying microtitanium plates with different lengths were measured by Mimics version 17.0 software (Materialise NV, Leuven, Belgium). A statistical regression and correlation analysis of relevant specification parameters of the microtitanium plate was then studied.

Results: As the size of the microtitanium plate increased, we found that the cross-sectional area of cervical spinal canal and distance between the descendants of the lamina and the distance of cervical spinal cord concordantly increased, and these data changes linearly. The regression equation associated with sagittal diameter, cross-sectional area, and posterior movement distance of the cervical spinal cord was obtained.

Conclusion: According to the correlation analysis of imaging data changes, the regression equation was obtained to guide the selection of microtitanium plates with appropriate specifications in a cervical vertebral dome expansion laminoplasty.

Key words: Cervical spinal stenosis; Laminar back distance; Medical imaging measurement; Miniature titanium plate; Spinal canal enlargement

Introduction

With the progression of modern society, cervical spondylosis has appeared to be one of the most common orthopedic diseases. It is caused by a reduction in the anteroposterior diameter and effective volume of the spinal canal[1]. Generally, patients with severe symptoms and signs need surgical treatment[2]. In 1977, Hirabayashi *et al.*[3] first proposed an internal fixation of a single open-door miniature titanium plate. After years of development, the internal fixation of a single open-door miniature titanium plate has achieved good clinical results and is now recognized by the majority of orthopedic specialists as one of the most commonly used methods for treating cervical spondylosis-related diseases. With the improvement of posterior cervical surgery, many scholars have improved and optimized the associated surgical methods.

Our team has also improved in this context. According to the principle and purpose of cervical spinal canal osteoplasty in the treatment of cervical spondylopathy, we have finally developed a cervical vertebral dome expansion laminoplasty. This type of surgery involves lavage of the lamina at the junction of the C_3-C_7 bilateral lamina and the facet

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joint and requires the lamina to be completely moved backward. In this process, we attempted to protect and retain the relevant tissue structures attached to the spinous process, such as the supraspinous ligament and interspinous ligament, while keeping the spinous process in the original center position and enlarging the spinal canal. This procedure permits the spinal cord to drift backward, thus reducing the pressure on the cervical spinal cord. Then, we used our own microtitanium plate to fix the two sides of the lamina to form a strong structure. These operations preserve the posterior muscle ligament complex of the cervical spine, which keeps the cervical spine in a stable state and reduces the occurrence of any complications that might include axial symptomology[4] (Fig. 1).

According to research by Zhao *et al*.,[5] 16 patients treated with the controllable dome-type laminectomy and posterior extension of the spinal canal improved significantly after surgery. The average JOA score at the last follow-up increased to 14.6 $\pm$ 1.4 points, the postoperative nerve function improvement rate was 87.23% $\pm$ 3.81%, and Frankel's grade also changed from D to E before the operation, indicating that the operation method is reliable and that the clinical effect is significant. According to the imaging data of the follow-up patients, it can be seen that the internal fixation of the titanium plate shows no looseness or breakage and there is no increase in the imaging manifestation of the spinal cord bulges than before.

During the cervical vertebral dome expansion laminoplasty, the posterior distance of the lamina determines the change in the anteroposterior diameter of the spinal canal, enlargement of the cross-sectional area of the spinal canal, and the distance of the spinal cord to drift backward. If the lamina is not adequately moved backward, then the spinal cord cannot be fully decompressed, and the clinical symptoms do not significantly improve. Additionally, if the distance of the posterior lamina movement is too large, the spinal cord will excessively drift backward, and the nerve roots will be significantly pulled as a result, which might then cause the occurrence of C_5 nerve root palsy symptoms. According to studies by Lubelski *et al*., the cervical spinal canal diameter is enlarged by 1 mm, and the probability of C_5 nerve root paralysis is increased by approximately 69%[6]. Therefore, an appropriate lamina posterior distance is crucial if clinical efficacy and recovery from the surgical procedure is to be realized. In addition, the distance of the posterior lamina movement depends on the structure of the vertebral body and the specifications of the custom microtitanium plate. The choice of differently sized microtitanium plates for different cervical segments will influence the achievement of different posterior lamina distances. Thus, a selection of suitable microtitanium plates for different internal cervical segments to enable strong internal fixation represents an important part and focus of study.

In the current study, we measured and analyzed CT and MRI data of 16 patients with the cervical vertebral dome expansion laminoplasty at our medical center. We measured the distance of the posterior lamina, the enlarged area of the spinal canal, and the drift distance of the spinal cord. The intent of the study was therefore to explore the correlation between the different types of microtitanium plates in different cervical segments in terms of the above three parameters. We also sought to establish guidance for the selection of suitable microtitanium plates in the setting of a posterior tracheal angioplasty with the aim of achieving improved surgical results and clinical efficacy.

Through the data analysis and correlation study of the changes in the cervical spine imaging data of these 16 patients underwent the cervical vertebral dome expansion laminoplasty, the purpose of this study is: (i) to clarify the

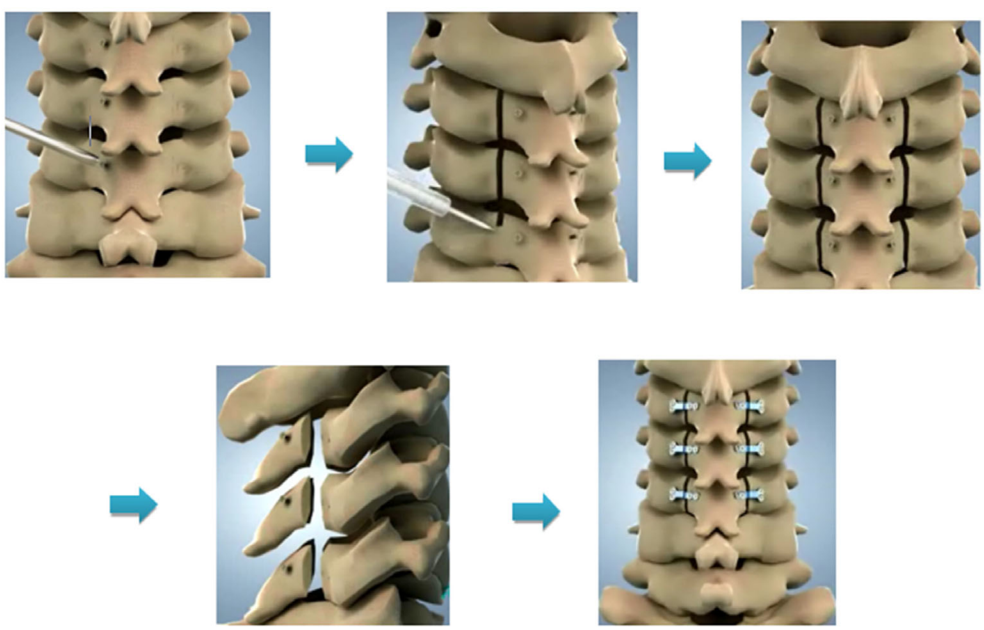

Fig. 1 Cervical vertebral dome expansion laminoplasty procedure diagram. This operation first cuts off both sides of the cervical lamina, and then moves the entire lamina back, and then fixes the cervical spinal cord with a titanium plate.

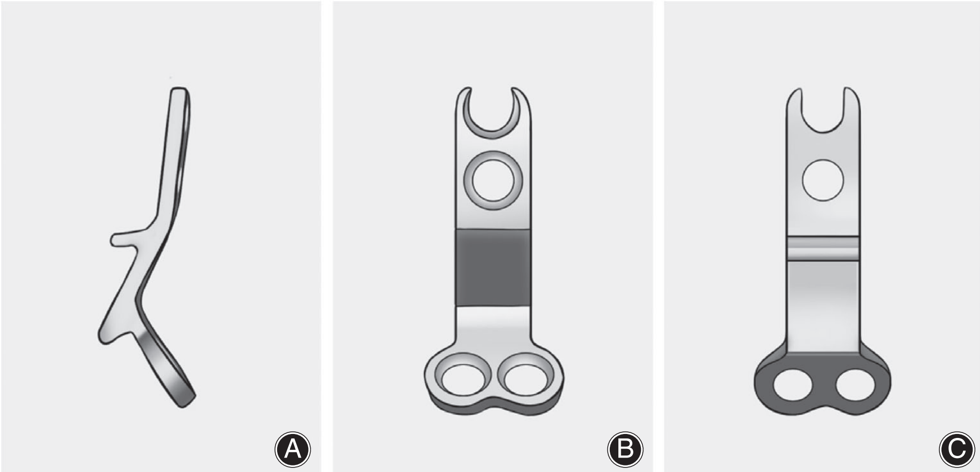

Fig. 2 Different types of cervical posterior microtitanium plates. There are three types of titanium plates used in this operation, and the corresponding specifications will be selected according to the operation situation. A, B, C shows the front, side and back of the cervical titanium plate.

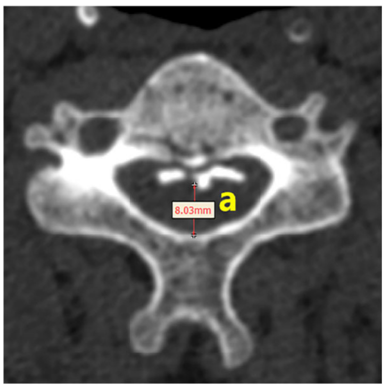

Fig. 3 Preoperative spinal anteroposterior diameter a. To measure the midpoint of the posterior margin of the vertebral body or the pathological mass to the midpoint of the posterior border of the spinal canal, which were recorded as "a".

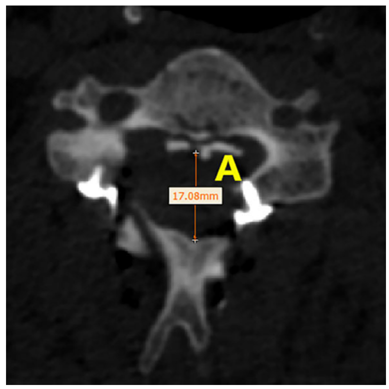

Fig. 4 Postoperative spinal anteroposterior diameter A. To measure the sagittal diameter of the spinal canal after completing a cervical vertebral dome expansion laminoplasty, which was recorded as "A".

correlation between different specifications of titanium plates and changes in the imaging data of the cervical spinal canal; (ii) to obtain the regression equation between the use of different specifications of titanium plates and the imaging changes of the cervical spinal canal; and (iii) to guide the selection and application of microtitanium plates specifications in a cervical vertebral dome expansion laminoplasty.

Materials and Methods

General Information

In February 2017 through September 2018, 16 patients that underwent the cervical vertebral dome expansion laminoplasty for the treatment of their cervical spinal cord were selected and recruited to the study on the basis of their medical records. The patients included 14 males and 2 females, which were aged 49–76 years, with a mean age of 57.3 ± 1.7 years. All 16 patients underwent cervical CT and

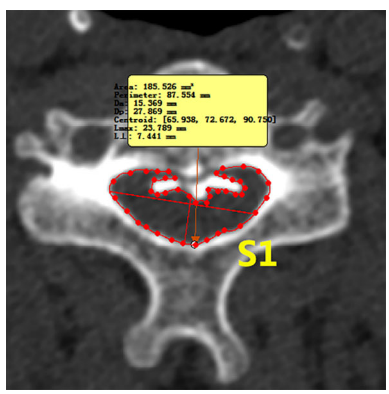

Fig. 5 Preoperative spinal canal cross-sectional area S_1. The cross-sectional area which the posterior border was the leading edge of the segmental lamina, and the inner edge of the pedicle on both sides served as the boundary between those sides was recorded as S_1.

MRI before and after surgery. The CT data were obtained in the DICOM format by a 0.5-row thin-layer scan of a 64-row CT machine.

Different types of custom cervical posterior micro-titanium plates were developed and selected for intraoperative application, and their dimensions are listed as follows: 27 × 4.5 × 1; 4 holes, 29 × 4.5 × 1; 4 holes, and 31 × 4.5 × 1; 4 holes (Fig. 2).

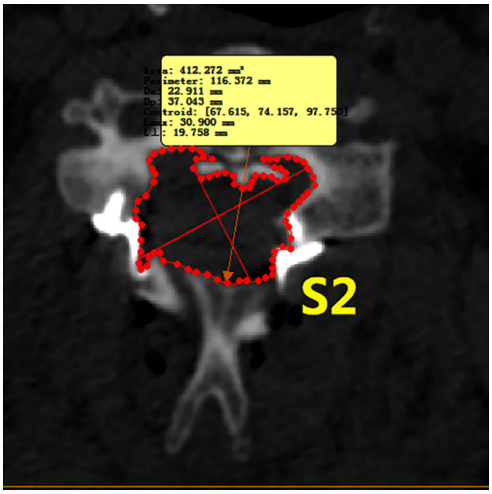

Fig. 6 Postoperative spinal canal cross-sectional area S2. The cross-sectional area of the spinal canal after the surgery is recorded as S2.

Inclusion and Exclusion Criteria

Inclusion Criteria

The inclusion criteria were as follows: (i) patients met the symptoms and signs of cervical spinal stenosis, confirmed by imaging and neurophysiological examinations; (ii) patients treated with cervical vertebral dome expansion laminoplasty; (iii) patients who completed preoperative and postoperative imaging examinations; (iv) the main evaluation indicators included diameter of the spinal canal, cross-sectional area of the spinal canal; and (v) a correlation research study.

Exclusion Criteria

The exclusion criteria were as follows: (i) patients with heart, brain, kidney, and other important organ diseases; (ii) patients with cervical spinal stenosis caused by acute trauma, spinal canal occupying lesions, and infection; and (iii) patients unable to cooperate with surgical treatment.

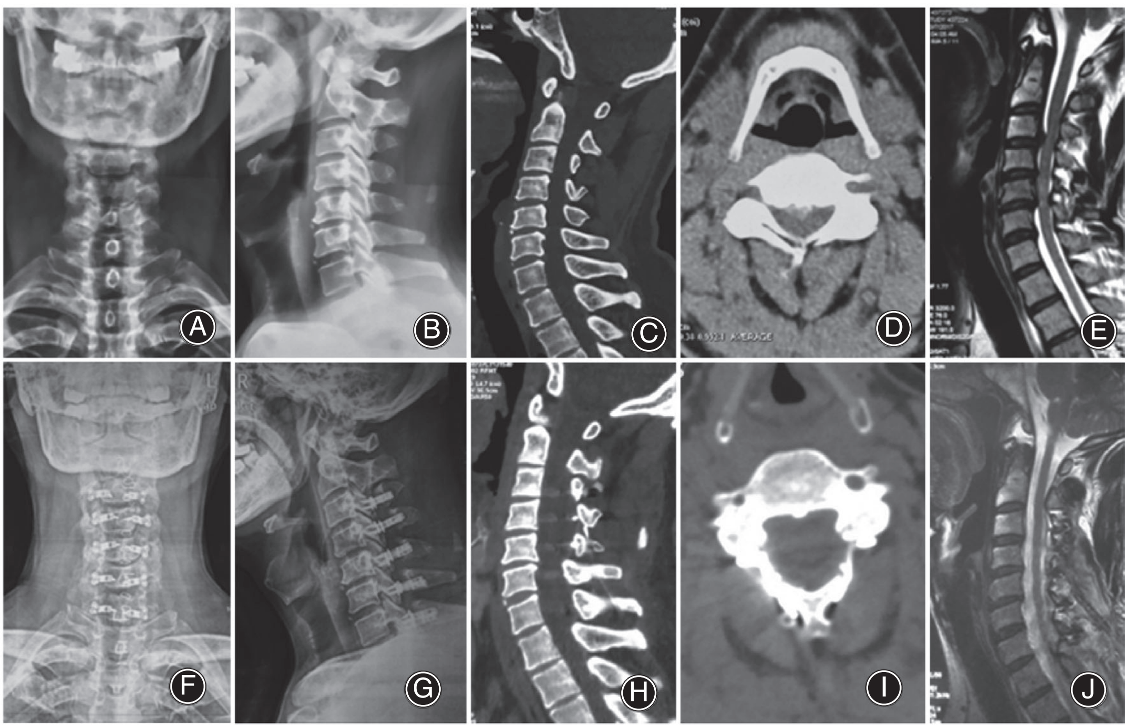

Fig. 7 A 54-year-old male with numbness and weakness in both upper limbs for 2 years was diagnosed with cervical spondylosis. (A and B) showed the condition before the cervical spine surgery, (F and G) showed the condition after the cervical spine surgery. (C, D and E) showed the cervical spinal canal stenosis, and the cervical spinal cord was compressed obviously. (H, I and J) showed that after cervical surgery, the cervical spinal canal was significantly enlarged and the spinal cord was no longer compressed.

Experimental Methods

The obtained DICOM data from the pre- and postoperative CT (DICOM formatted data was obtained from a 0.5-row CT 0.5-mm thin-layer scan) were imported into Mimics version 17.0 software for measuring the desired data, including the measurement of the anteroposterior diameter of the spinal canal and the cross-sectional area of the spinal canal when using a small titanium plate in different cervical segments. The distance of the spinal cord drifting back in different cervical segments was measured using Photoshop CS5 software (Adobe Inc., San Jose, California).

Data of the Cervical Posterior Lamina Retraction Distance

Mimics version 17.0 software was used to: (i) measure the sagittal diameter of the midpoint of the vertebral pedicle in the midpoint of the $C_{3\text{-}7}$ segment; and (ii) measure the midpoint of the posterior margin of the vertebral body or the pathological mass to the midpoint of the posterior border of the spinal canal, which were recorded as "a." The same method was used to measure the sagittal diameter of the spinal canal after completing a cervical vertebral dome expansion laminoplasty, which was recorded as "A." Thus, the lamina back movement distance was determined as "A-a"(Figs 3 and 4)..

Data of the Change in Cervical Spinal Canal Cross-Sectional Area

Using Mimics version 17.0 software to measure the cross-sectional area (CSA) of the midpoint plane of the cervical vertebral pedicle in each segment of $C_{3\text{-}7}$, we found that when taking measurements, the anterior border of the spinal canal was the posterior edge of the vertebral body or the trailing edge of the pathological mass. In addition, the posterior border was the leading edge of the segmental lamina, and the inner edge of the pedicle on both sides served as the boundary between those sides. The cross-sectional area was recorded as S1, and the same method was used to measure the CSA of the enlarged spinal canal after the new, full backward shift of the lamina in the spinal canal, which was recorded as S2. The increased CSA of the spinal canal was recorded as S2-S1 (Figs 5 and 6).

Data of the Spinal Cord Posterior Distance in the Cervical Spinal Canal

Measuring the distance of the spinal cord by Photoshop CS5 software, we used the midpoint of the posterior wall of the vertebral body as the starting point. Alternatively, if there was an occupying pathological tissue, the midpoint of the occupying tissue in the spinal canal was used as the starting point of measurement. Using the sagittal midpoint of the cervical spinal cord as the measurement endpoint, we recorded the distance between both of these points. The distance from the midpoint of the spinal cord to the posterior wall of the vertebral body was recorded and defined as "c"; the same method was used to measure the distance between the two points by MRI after completing the cervical vertebral dome expansion laminoplasty, wherein the distance

TABLE 1 Relationship between the different cervical vertebra segments as they related to the spinal canal parameters and microtitanium plate specifications

Microtitanium plate specifications	Laminar back distance (mm)			Expanded area of spinal canal (mm^2)			Spinal backward drift distance (mm)		
	Type 27	Type 29	Type 31	Type 27	Type 29	Type 31	Type 27	Type 29	Type 31
C_3	4.131 ± 0.051	4.265 ± 0.066	—	91.210 ± 2.435	95.340 ± 2.133	—	3.276 ± 0.039	3.354 ± 0.009	—
C_4	6.665 ± 0.096	6.838 ± 0.015	7.010 ± 0.170	156.630 ± 4.082	160.720 ± 4.235	171.840 ± 4.338	3.580 ± 0.097	3.670 ± 0.104	3.960 ± 0.153
C_5	—	11.480 ± 0.172	12.155 ± 0.210	—	230.830 ± 5.573	244.655 ± 3.948	—	4.540 ± 0.079	4.737 ± 0.044
C_6	9.780 ± 0.234	9.830 ± 0.251	10.560 ± 0.228	183.740 ± 7.071	191.940 ± 4.538	199.630 ± 4.458	4.080 ± 0.071	4.160 ± 0.071	4.340 ± 0.083
C_7	9.582 ± 0.100	9.790 ± 0.169	10.240 ± 0.100	146.636 ± 5.289	160.870 ± 6.241	165.30 ± 6.123	3.865 ± 0.066	4.070 ± 0.093	4.180 ± 0.099

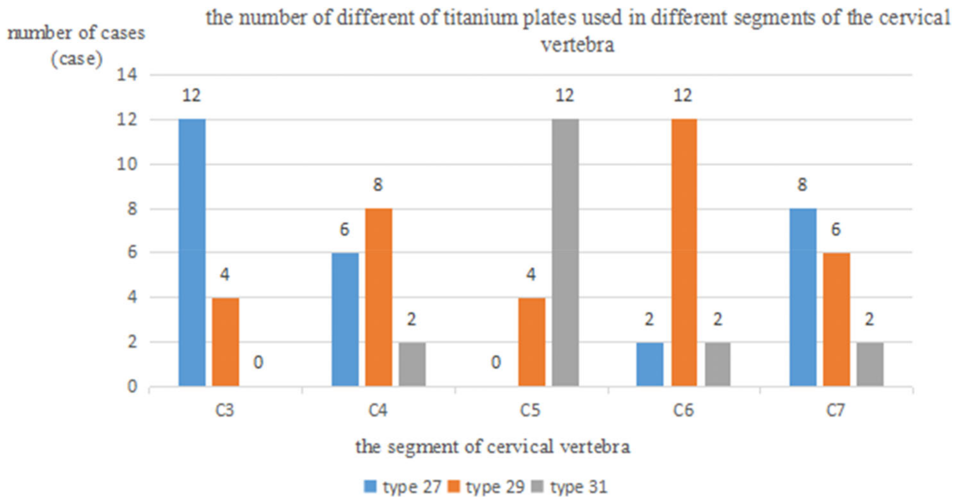

Fig. 8 Number of different titanium plates used in different segments of the cervical vertebra.

between the front end of the spinal cord and the posterior wall of the vertebral body was recorded as "C." Thus, the distance of the cervical spinal cord was defined as C-c.

Statistical Methods

All data were statistically analyzed by SPSS version 17.0 software. Data are expressed as the mean plus/minus the standard deviation about the mean ($\hat{X} \pm SD$). Pearson's correlation analysis was performed to observe the relationship between the different segmental lamina posterior distances, spinal canal enlargement, and backward drift distance of the cervical spinal cord with different specifications of microtitanium plates. Pearson's correlation analysis was also used to peform a linear regression to establish a regression equation of the measured data.

Results

All 16 patients were safely and successfully treated by surgery. The clinical outcome was good following the surgical procedure. One of the patients had symptoms of C5 nerve root palsy, and the painful symptoms were significantly relieved by conservative treatments, such as nutritional nerve treatment. The symptoms disappeared completely after 2 months postsurgery (Fig. 7).

The following are the number of titanium plates used in the cervical vertebrae and the relationship between the different cervical vertebra segment-related spinal canal parameters and microtitanium plate specifications. The posterior laminar distance of each segment, the enlarged area of the spinal canal, and the posterior movement distance of the cervical spinal cord increased with increasing size of the microtitanium plate, as shown in Table 1 and fig. 8.

Pearson's correlation analysis was used to compare the relationship between the lamina posterior distance, spinal canal enlargement, cervical spinal cord backward drift distance and titanium plates with different specifications (Table 2). It was found that the different specifications of microtitanium plates had the following significant effects on the posterior movement distance of the lamina: C_3 was 0.771 ($P < 0.05$), C_4 was 0.863 ($P < 0.05$), C_5 was 0.823 ($P < 0.05$), C_6 was 0.842 ($P < 0.05$), and C_7 was 0.869 ($P < 0.05$). The enlarged area of the C_3 spinal canal was 0.789 ($P < 0.05$), C_4 was 0.862 ($P < 0.05$), C_5 was 0.845 ($P < 0.05$), C_6 was 0.880 ($P < 0.05$), and C_7 was 0.784 ($P < 0.05$). The backward drift distance of the cervical spinal cord at C_3 was 0.829 ($P < 0.05$), C_4 was 0.908 ($P < 0.05$), C_5 was 0.896 ($P < 0.05$), C_6 was 0.935 ($P < 0.05$) and C_7 was 0.852 ($P < 0.05$).

Establishing correlation equations. The regression equations for the different posterior distances of the cervical vertebrae and the microtitanium plate specifications are as follows:

C_3: $\hat{Y} = 0.067 + 2.326X$ ($R^2 = 0.594$), C_4: $\hat{Y} = 0.086 + 4.335X$ ($R^2 = 0.746$), C_5: $\hat{Y} = 0.337 + 1.698X$ ($R^2 = 0.678$), C_6: $\hat{Y} = 0.219 + 3.592X$ ($R^2 = 0.710$), C_7: $\hat{Y} = 0.146 + 5.628X$ ($R^2 = 0.755$).

The regression equations for the different cervical segmental canal enlargement areas and microtitanium plate specifications are as follows:

C_3: $\hat{Y} = 2.065 + 35.455X$ ($R^2 = 0.622$), C_4: $\hat{Y} = 3.420 + 62.750X$ ($R^2 = 0.743$), C_5: $\hat{Y} = 6.912 + 30.373X$ ($R^2 = 0.713$), C6: $\hat{Y} = 3.955 + 77.175X$ ($R^2 = 0.774$), C7: $\hat{Y} = 5.405 + 0.952X$ ($R^2 = 0.614$).

The regression equations for the backward drift distance of the cervical spine segments and the specifications of the microtitanium plates are shown below:

C_3: $\hat{Y} = 0.039 + 2.230X$ ($R^2 = 0.686$), C_4: $\hat{Y} = 0.084 + 1.265X$ ($R^2 = 0.824$), C_5: $\hat{Y} = 0.098 + 1.685X$ ($R^2 = 0.802$), C_6: $\hat{Y} = 0.068 + 2.189X$ ($R^2 = 0.874$), C_7: $\hat{Y} = 0.086 + 1.545X$ ($R^2 = 0.727$).

Discussion

Effectiveness of the Cervical Vertebral Dome Expansion Laminoplasty

The cervical vertebral dome expansion laminoplasty was performed by moving the lamina as a whole and using a custom microtitanium plates with different specifications for internal fixation. At the same time, the volume of the spinal canal was enlarged and the spinal cord drifted backward, thereby alleviating clinical symptoms; thus, the clinical curative effect was highly acceptable. According to Zhao's research[5], the clinical efficacy of this surgical method could be clarified. However, different sizes of microtitanium plates can provide different distances of posterior lamina movement, consequently affecting the enlarged areas of the spinal canal and the backward drift of the cervical spinal cord. Therefore, the selection of a microtitanium plate with a suitable size in different cervical segments is essential for the surgical treatment of cervical spondylosis.

Sodeyama *et al.*[7] found that after posterior cervical surgery, the distance of the spinal cord to the dorsal side ranged from 0 to 6.6 mm, and the clinical effect was only evident when the spinal cord was moved more than 3 mm. At the same time, relevant research has also shown[8–10] that the sagittal diameter of the spinal canal can achieve better clinical efficacy when expanded by 4–5 mm. According to research by Imagama *et al.*,[11] when the posterior distance of the C_5 segment in the spinal cord exceeded 5 mm, the probability of seeing C_5 nerve root paralysis symptoms was significantly greater than that of a cervical spinal cord posterior movement distance of less than 5 mm. Therefore, the range of the posterior movement of the lamina is 4–5 mm, and when the spinal cord drifts more than 3 mm, a good clinical effect is possible.

Selection of a microtitanium plate

With the use of a regression equation analysis in this study, we found that the C_3 segment uses a microtitanium plate with a specification of 27 × 4.5 × 1 with four holes, which can achieve a posterior laminar movement distance of 4.634.131 ± 0.051 mm and a spinal retraction distance of 3.276 ± 0.039 mm. The C_4 segment uses a microtitanium plate with a specification of 29 × 4.5 × 1; four holes, which can achieve a posterior laminar movement distance of 6.838 ± 0.015 mm and a backward spinal cord movement of 3.670 ± 0.104 mm. The C_5 segment uses a microtitanium plate with a specification of 31 × 4.5 × 1; four holes, which can achieve a posterior laminar movement distance of 12.155 ± 0.210 mm and a backward spinal cord movement distance of 4.737 ± 0.044 mm. The C_6 segment uses a microtitanium plate specification of 31 × 4.5 × 1; four holes, which can achieve a posterior lamina movement of 9.830 ± 0.251 mm and a backward spinal cord movement distance of 4.160 ± 0.071 mm. The C_7 segment uses a microtitanium plate specification of 31 × 4.5 × 1; four holes, which can achieve a posterior lamina movement of 9.582 ± 0.100 mm and a backward spinal movement distance of 4.160 ± 0.071 mm.

The use of microtitanium plates with a specification of 27 × 4.5 × 1; four holes in the C_3 segment can achieve good clinical results. The same clinical effect can be achieved by using the 29 × 4.5 × 1; four holes microtitanium plate in the C_4 segment, the 31 × 4.5 × 1; four holes microtitanium plate in the C_5 segment, the 29 × 4.5 × 1; 4 holes microtitanium plate in the C_6 segment, or 27 × 4.5 × 1; four holes the microtitanium plate in the C_7 segment.

Similarly, according to the regression equations obtained in this study, the operator can calculate and predict the parameters of the posterior movement distance of the cervical vertebrae obtained when using different sizes of microtitanium plates for different segments of the cervical vertebra; thus, it is possible to select the most suitable microtitanium plate for surgical treatment.

In this study, one patient developed C_5 nerve root palsy after surgery. We consider that it was related to the excessive distance of the posterior lamina movement caused by the selection of a microtitanium plate that was too large during the operation, thus causing an excessive drift of the cervical spinal cord. Imagama *et al.*[11] found that 43 patients had obvious symptoms of C_5 nerve root palsy through an imaging study of 1858 patients undergoing posterior cervical surgery. The average distance of the cervical spinal cord was 3.9 mm. In this patient, a miniature titanium plate with a specification of 31 × 4.5 × 1; four holes were selected in the C_5 segment. The posterior vertebral plate distance was 12.79 mm, the enlarged area of the spinal canal was 184.56 mm^2, and the cervical spinal cord was moved backward by 5.13 mm. Through the regression equation, we found that for this patient in this cervical segment, the selection of a microtitanium plate with a specification of 29 × 4.5 × 1; four holes could achieve the ideal clinical effect, which indicates the necessity of this study.

This study further clarified the most suitable titanium plate size for use in different cervical segments. Based on the results of the study, we recommend the use of the cervical vertebral dome expansion laminoplasty procedure for the treatment of cervical spondylosis with the use of the following microtitanium plates: 27 × 4.5 × 1; four holes in the C_3 segment, 29 × 4.5 × 1; four holes in the C_4 segment, 31 × 4.5 × 1; four holes in the C_5 segment, 29 × 4.5 × 1; four holes in the C_6 segment, and 27 × 4.5 × 1; four holes in the C_7 segment. Of course, when the impact of the surgical operation is excluded[12], the specifications of the microtitanium plate should be flexibly selected according to the individual anatomy of the patient and the pathological condition. In summary, the cervical vertebral dome expansion laminoplasty can effectively increase the posterior lamina distance, enlarged area of the spinal canal, and backward drift distance of the spinal cord. In addition, the custom dome-type microtitanium plates plays a vital role in the strong internal fixation of the cervical vertebra.

Limitations

The sample size in this study was relatively small. Therefore, future studies should compare the data of more patients. The regression equation between the changes in the imaging data of the cervical spinal canal and the specifications of the microtitanium plate was obtained. However, some patients with congenital cervical spinal stenosis cannot be generalized. Preoperative evaluation should be carried out based on actual imaging data to prevent related complications.

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