



Effect of posterior cervical expansive open-door laminoplasty on cervical sagittal balance

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Abstract

Purpose Posterior cervical expansive open-door laminoplasty (LAMP) is a mature surgical procedure for the treatment of cervical spondylotic myelopathy (CSM), but there are few studies on the changes in cervical sagittal balance. This study aimed to analyze the imaging and clinical data of patients who underwent LAMP and to explore the effect of this procedure on the cervical sagittal balance.

Methods This was a retrospective study of the patients who underwent LAMP between 01/2014 and 12/2017. The C0–C2 Cobb angle, sagittal vertical angle (SVA), C2–C7 Cobb angle, and T1-slope were measured. The Japanese Orthopaedic Association (JOA) score, neck disability index (NDI), and visual analog scale (VAS) were used.

Results There were 69 males and 39 females. The mean age was 61.3 ± 5.3 years. The C0–C2 Cobb angle increased from $11.3 \pm 5.5^\circ$ to $26.8 \pm 4.8^\circ$ ($P=0.186$). The C2–C7 Cobb angle decreased from $13.9 \pm 8.6^\circ$ to $10.65 \pm 10.7^\circ$ ($P=0.016$). SVA increased from 21.0 ± 5.8 mm to 25.4 ± 11.5 mm ($P=0.001$). The preoperative average JOA score was 11.1 ± 2.2 points, and the postoperative score was 14.0 ± 2.1 points, with an average improvement rate of JOA of $46.5 \pm 3.8\%$. The NDI score decreased from preoperative 15.6 ± 5.4 points to 11.3 ± 7.9 points, and the VAS score was decreased from 4.6 ± 1.8 points to 3.3 ± 1.6 points (all $P < 0.05$).

Conclusion LAMP improved the neurological function and quality of life of patients with CSM. The cervical vertebrae show a tendency of tilting forward, suggesting that overextension of the upper cervical vertebra might be used to maintain the center of gravity of the skull and horizontal vision.

Keywords Cervical vertebrae · Spinal cord diseases · Laminoplasty · Postural balance

Introduction

Cervical spondylotic myelopathy (CSM) is caused by spinal cord compression or radiculopathy, typically characterized by neck pain, and sensory, motor, and/or reflex deficits [1–3]. CSM is also characterized by difficulty with manual dexterity, upper extremity numbness, weakness, gait disturbance, upper motor neuron signs such as Hoffman sign, ataxia, hyperreflexia, urinary urgency, and clonus [1, 2].

The incidence of CSM is about 4 per 100,000 person-years [4]. The underlying pathology of CSM is usually degenerative [1, 3]. After ruling out red flags such as a tumor, infection, and degenerative disorders, most patients recover with conservative treatments, but surgery is indicated in patients unresponsive to medical treatment, definite cervical-root compression at imaging, progressive or disabling neurological deficit, and spinal instability [1–3, 5, 6].

Posterior cervical expansive open-door laminoplasty (LAMP) is a mature surgical procedure for the treatment of CSM and achieves good long-term outcomes [7, 8]. The advantages of this technique include a direct posterior decompression effect and an indirect anterior decompression effect, which is caused by the backward shifting of the spinal cord [9, 10]. Given there is no need for interbody fusion, LAMP is especially suitable for elderly patients with multiple-level CSM [11].

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The sagittal spinal balance is an important factor affecting the efficacy and quality of life (QOL) after LAMP. As the spinal part with the largest activity, the cervical sagittal balance is receiving increasing attention [12]. Studies have shown that it can lead to a decreased angle of cervical lordosis regardless of the treatment methods for CSM [13], but there are few studies on the changes in cervical sagittal balance.

Therefore, the aim of this retrospective study retrospectively was to analyze the imaging and clinical data of patients who underwent LAMP and to explore the effect of this procedure on the cervical sagittal balance. The analysis of the imaging parameters related to cervical sagittal balance and their associations with indicators of clinical recovery could offer guidance for clinical work.

Methods

Patients

This was a retrospective study of the patients who underwent LAMP between January 2014 and December 2017. The inclusion criteria were: (1) imaging and neuroelectrophysiologic examinations suggested developmental cervical spinal stenosis, multilevel cervical disc herniation, and ossification of the posterior longitudinal ligament (OPLL); (2) complicated with obvious signs of spinal cord injury; and (3) underwent LAMP. The exclusion criteria were: (1) patients needing combined anterior surgery in the first or second stage; (2) patients with obvious cervical kyphosis; (3) disc herniation and giant osteophytes accounting for 60% of the spinal canal [14]; (4) tumors, tuberculosis, or trauma; or (5) incomplete follow-up or imaging data.

The patients were grouped according to the median of the preoperative *T1*-slope angle: high *T1*-slope group and low *T1*-slope group.

This study was approved by the ethics committee. Informed consent was waived due to the retrospective nature of the study.

LAMP operation

All surgeries were routinely performed by the same chief physician (Dr. XM) (with 30 years of experience). During the study period, the use of an anterior or posterior approach was mainly decided according to the radiographic parameters of sagittal alignment. When the *T1*-slope was far $> 25^\circ$, an anterior approach was considered. When the *C2*–*7* SVA was > 40 mm, an anterior approach was also considered. The posterior middle approach was performed to longitudinally cut the skin and subcutaneous tissues in sequence, exposing the deep fascia.

Subperiosteal decollement of the bilateral paraspinous muscles was performed to expose the spinous process, bilateral vertebral plates, and medial part of the articular process. For ease of operation, the right side was selected as the hinge side. The medial margin of the articular process at the bilateral vertebral plates was grooved to remove the cortical bone and part of the cancellous bone, and the inner cortex was retained. At the opening side, the removal was performed to the inner cortex. Two vertebral plate grippers were used to simultaneously grip the vertebral plate edge on the hinge and opening sides. With the hinge side as the fulcrum, the vertebral plate was slowly and gently turned to the hinge side. A periosteal detacher was used for the auxiliary distraction of the opening side along the inner edge of the lateral mass in order to achieve an appropriate opening distance, which was usually 10 mm; the opening angle of the vertebral plate was mostly 40° . Titanium plates of suitable size were separately fixed on the lateral mass and vertebral plate. The position of the titanium plates was adjusted and fixed by screws, confirmed by *G*-arm fluoroscopy. A negative pressure drainage tube was indwelt. A neck brace was used for 4–6 weeks. Neck functional exercises were done as early as possible.

Data collection

Baseline data, imaging data (*C0*–*C2* Cobb angle, SVA, *C2*–*C7* Cobb angle, and *T1*-slope), and postoperative improvement of neurological function and QOL assessment indicators (Japanese Orthopaedic Association [JOA], neck disability index [NDI], and visual analogue score for pain [VAS]) were extracted from the medical charts.

Imaging evaluation

The patients underwent standard anteroposterior and lateral cervical X-ray examination before surgery and at the last follow-up. Two orthopedists who had not participated in the study measured four parameters related to cervical sagittal balance on the cervical X-ray films. The average value of the measurement results was taken. The measured parameters related to cervical sagittal balance included: *C0*–*C2* Cobb angle (angle A in Fig. 1, the angle between the skull base and the *C2* vertebral endplate plane), sagittal vertical axis (SVA) (Fig. 1b,c distance, distance from the SVA of the *C2* vertebral body to the posterior superior edge of the *C7* vertebral body), *C2*–*C7* Cobb angle (angle D in Fig. 1, the medial angle formed by the tangent lines of the inferior edges of the *C2* and *C7* vertebral bodies), and *T1*-slope (angle E in Fig. 1, the angle between the extended line and horizontal line for the superior edge of the *T1* vertebral body).

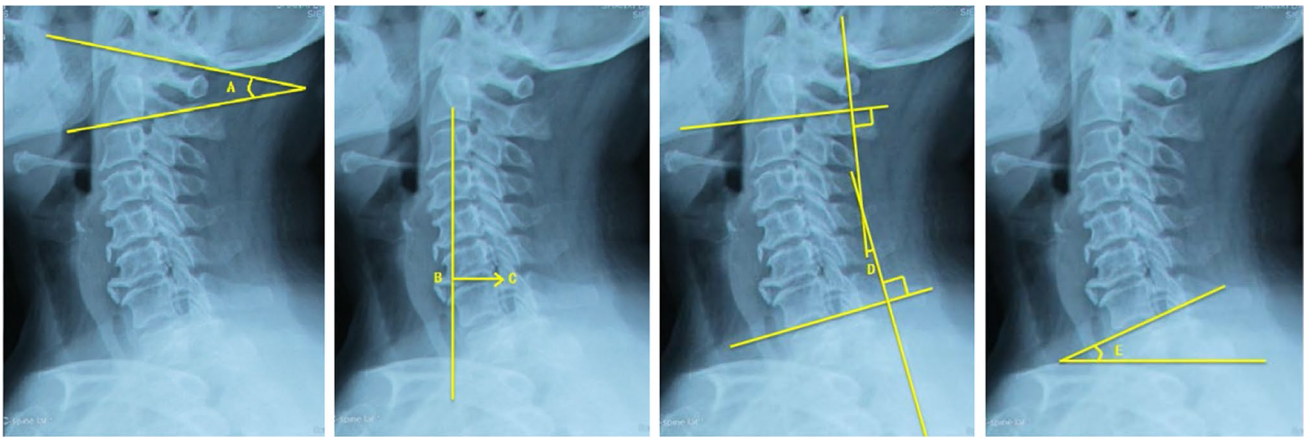


Fig. 1 Imaging parameters of the cervical sagittal view. **a** is the angle between the skull base and the C2 vertebral endplate plane. The **b**, **c** distance is the distance from the sagittal vertical axis of the C2 vertebral body to the superior posterior edge of the C7 vertebral body. **d** is

the angle formed by the tangent lines of the inferior edges of the C2 and C7 vertebral bodies. **e** is the crossing angle between the extended line and horizontal line for the superior edge of the T1 vertebral body

Surgical outcomes and QOL

The JOA score was used to assess the improvement of neurological function [15]. A JOA improvement rate of 100% indicated being cured; > 60% indicated markedly effective; 25–60% indicated effective; and < 25% indicated ineffective. The NDI was used to assess the functional status of the patient's neck [16], with a total score ranging from 0 (no disability) to 50 points (total disability). The VAS was used to assess axial symptoms, namely the degree of neck pain [17]. The patient indicated his degree of pain on a 10-cm line, with 0 indicating no pain and 10 indicating severe pain; 0–2 points indicated comfort; 3–4 mild pain; 5–6 moderate pain; 7–8 severe pain; and 9–10 extreme pain.

Follow-up

The routine follow-up period was 2 years after surgery, including visits at 1 week and 1, 3, 6, 12, 18, and 24 months. The follow-up was performed by outpatient visits to collect the T1-slope, SVA, C0–2 Cobb, C2–7 Cobb, JOA score, NDI score, and VAS score.

Statistical analysis

The SPSS 22.0 software (IBM, Armonk, NY, USA) was used for analysis. Continuous variables were tested for normal distribution using the Kolmogorov–Smirnov test. Continuous variables are presented as means \pm standard deviations and were tested using the independent-samples t test. Categorical data are presented as numbers and percentages and were analyzed using the chi-square test or Fisher's exact test, as appropriate. The correlations between C0–C2 Cobb and SVA, T1-slope, and SVA, and T1-slope and C2–C7

Cobb were analyzed by bivariate correlation analysis (Pearson). Two-sided *P* values < 0.05 were considered statistically significant.

Results

Baseline data

A total of 108 patients were included in the study. There were 69 males and 39 females. The mean age was 61.3 ± 5.3 years (range, 39–84 years). There were 64 patients with multi-level CSM, 35 with OPLL, and nine with developmental or degenerative cervical spinal stenosis. The patients were followed for 24 (24–48) months. There were no differences between the low and high T1-slope groups regarding the demographic and clinical characteristics (Table 1).

Improvement of neurological function and QOL assessment

The preoperative average JOA score was 11.1 ± 2.2 points, and the postoperative score was 14.0 ± 2.1 points, with an average improvement rate of JOA of $46.5 \pm 3.8\%$. The NDI score decreased from preoperative 15.6 ± 5.4 points to 11.3 ± 7.9 points, and the VAS score was decreased from 4.6 ± 1.8 points to 3.3 ± 1.6 points (all *P* < 0.05) (Table 1).

Assessment of parameters related to cervical sagittal balance

The C0–C2 Cobb angle increased from $11.3 \pm 5.5^\circ$ to $12.6 \pm 4.5^\circ$ (*P* = 0.001). The C2–C7 Cobb angle decreased from $13.9 \pm 8.6^\circ$ to $10.65 \pm 10.7^\circ$ (*P* = 0.016).

Table 1 Characteristics and outcomes of the patients

	Total	High T1-slope (n=54)	Low T1-slope (n=54)	P
Age, years	61.3±5.3	59.7±4.4	62.9±5.6	0.486
Male, n (%)	69:39	31:23	26:28	0.751
Pre-operation				
T1-slope	27.4±5.1	30.2±4.5	24.6±3.9	0.546
C0–C2 Cobb, °	11.3±5.5	12.8±4.9	9.7±5.7	0.167
C2–C7 Cobb, °	13.9±8.6	18.9±8.2	9.0±5.7	0.321
C2–C7 SVA, mm	21.0±5.8	22.4±1.0	19.6±7.9	0.268
JOA	11.1±2.2	10.8±2.7	11.4±1.6	0.155
NDI	15.6±5.4	15.8±5.3	14.5±5.4	0.119
VAS	4.6±1.8	4.9±2.3	4.2±1.0	0.314
Post-operation (24 months)				
T1-slope	26.8±4.8	29.7±4.4	23.9±3.2	0.103
C0–C2 Cobb, °	12.6±4.5*	15.2±3.3	10.5±4.4	0.014
C2–C7 Cobb, °	10.65±10.7*	13.9±10.2	7.4±10.6	0.001
C2–C7 SVA, mm	25.4±11.5*	26.9±11.4	23.8±11.6	0.066
JOA	14.0±2.1*	13.8±1.3	14.1±2.7	0.169
NDI	11.3±7.9*	10.8±6.8	11.7±3.1	0.247
VAS	3.3±1.6*	4.0±1.6	2.5±1.3	0.013
Operation time, min	102.5±17.8	100±20	105±15	0.541
Blood loss, ml	225±55.7	200±50	250±50	0.462
Follow-up, months	24	24	24	
Operation segments	C2–7	C2–7	C2–7	

*; compare with pre-operation $P < 0.05$

SVA sagittal vertical angle; JOA Japanese Orthopaedic Association; NDI neck disability index; VAS visual analog scale

SVA increased from 21.0 ± 5.8 mm to 25.4 ± 11.5 mm (all $P < 0.001$) (Table 1). There was no significant difference in the change of T1-slope. The increased C0–C2 Cobb angle was positively correlated with SVA after surgery ($r = 0.420$, $P = 0.015$). At 1 week after surgery, compared with the low T1-slope group, the high T1-slope showed larger C0–C2 Cobb angle ($12.5 \pm 4.2^\circ$ vs. $11.2 \pm 3.4^\circ$, $P = 0.028$) and larger C2–C7 Cobb angle ($17.2 \pm 5.8^\circ$ vs. $8.1 \pm 7.1^\circ$, $P = 0.046$). At 24 months after surgery, compared with the low T1-slope group, the high T1-slope showed larger C0–C2 Cobb angle ($15.2 \pm 3.3^\circ$ vs. $10.5 \pm 4.4^\circ$, $P = 0.014$), larger C2–C7 Cobb angle ($13.9 \pm 10.2^\circ$ vs. $7.4 \pm 10.6^\circ$, $P = 0.001$), and higher VAS for pain (4.0 ± 1.6 vs. 2.5 ± 1.3 , $P = 0.013$) (Table 2).

The preoperative average angle was $30.2 \pm 4.5^\circ$ in the high T1-slope group and $24.6 \pm 3.9^\circ$ in the low T1-slope group (Table 3). Compared with before operation, the C0–C2 Cobb angle and SVA were increased, and the C2–C7 Cobb angle was decreased after surgery, but there were no significant differences in the three parameters between the high and low T1-slope group (Table 3). Similarly, neurological function and QOL were significantly improved in the two groups, but there were no significant differences in the VAS scores between the low T1 and high T1 groups (Table 3).

Discussion

C2–C7 SVA is an important parameter for predicting the postoperative outcome of posterior cervical surgery. Elevated spinal intramedullary pressure was associated with an increase in SVA [18]. The change in the JOA score was negatively correlated with SVA and positively correlated with the volume change of the cervical spinal cord [12]. SVA > 40 mm can significantly affect the NDI, thus affecting the surgical effect [13]. In this study, postoperative SVA was increased compared with before surgery, showing a tendency of tilting forward of the cervical vertebra, as observed after anterior cervical hybrid decompression and fusion [19]. Nevertheless, the neurological function and QOL of patients after surgery were improved, which could be due to the average SVA after surgery is only 28 mm, far below the critical value of 40 mm [13]. Postoperative MRI showing that the backward shifting of the cervical spinal cord > 3 mm could indicate a good [20]. Therefore, cervical vertebrae tilting forward did not have a significant effect on surgical outcomes.

Among the many assessment parameters of the cervical sagittal balance, the T1-slope is a useful parameter recently introduced and is important for assessing the overall sagittal

Table 2 Outcome indicators after surgery

	High T1-slope (n=54)	Low T1-slope (n=54)	P
T1-slope			
1 week	32.1±3.7	23.1±2.5	0.099
24 month	29.7±4.4	23.9±3.2	0.103
C0–C2 Cobb, °			
1 week	12.5±4.2	11.2±3.4	0.028
24 months	15.2±3.3	10.5±4.4	0.014
C2–C7 Cobb, °			
1 week	17.2±5.8	8.1±7.1	0.046
24 months	13.9±10.2	7.4±10.6	0.001
C2–C7 SVA, mm			
1 week	24.4±8.6	22.5±9.1	0.085
24 months	26.9±11.4	23.8±11.6	0.066
JOA			
1 week	11.2±1.7	12.3±2.0	0.215
24 months	13.8±1.3	14.1±2.7	0.169
NDI			
1 week	12.9±5.7	12.8±5.2	0.102
24 months	10.8±6.8	11.7±3.1	0.247
VAS			
1 week	4.2±1.8	3.6±1.4	0.156
24 months	4.0±1.6	2.5±1.3	0.013

SVA sagittal vertical angle; JOA Japanese Orthopaedic Association; NDI neck disability index; VAS visual analog scale

Table 3 Subgroup analyses

	Pre-op	24 months	P value
High T1-slope			
T1-slope	30.2±4.5	29.7±4.4	0.078
C0–C2 Cobb, °	12.8±4.9	15.2±3.3	0.034
C2–C7 Cobb, °	18.9±8.2	13.9±10.2	0.022
C2–C7 SVA, mm	22.4±1.0	26.9±11.4	0.013
JOA	10.8±2.7	13.8±1.3	0.037
NDI	15.8±5.3	10.8±6.8	0.035
VAS	4.9±2.3	4.0±1.6	0.020
Low T1-slope			
T1-slope	24.6±3.9	23.9±3.2	0.066
C0–C2 Cobb, °	9.7±5.7	10.5±4.4	0.059
C2–C7 Cobb, °	9.0±5.7	7.4±10.6	0.044
C2–C7 SVA, mm	19.6±7.9	23.8±11.6	0.017
JOA	11.4±1.6	14.1±2.7	0.026
NDI	14.5±5.4	11.7±3.1	0.019
VAS	4.2±1.0	2.5±1.3	0.014

SVA sagittal vertical angle; JOA Japanese Orthopaedic Association; NDI neck disability index; VAS visual analog scale

balance of the spine, reflecting the degree of kyphosis at the cervicothoracic junction [21]. Some studies have shown that the T1-slope has a strong correlation with SVA ($r=0.655$, $P<0.01$) [22, 23], which, however, was not observed in the present study ($r=0.023$, $P=0.118$). Kim et al. [23] reported that a high T1-slope was a risk factor for kyphosis after laminoplasty. Knott et al. [22] showed that it is difficult to maintain the cervical sagittal balance when the T1-slope is $>25^\circ$ or $<13^\circ$ [22]. Nevertheless, it has recently been reported that the preoperative T1-slope angle does not affect or aggravate the changes in the cervical sagittal balance [24]. Therefore, the effect of the T1-slope on the changes in the cervical sagittal axis after laminoplasty remains unclear. The present study showed that the preoperative average T1 slope was 27.4° and that it was not significantly changed after surgery. Thus, the T1-slope may be unique to each individual. At the same time, this study found that before surgery, the high T1-slope group had a large C2–C7 Cobb angle, and the low T1-slope group had a small C2–C7 Cobb angle. Moreover, after surgery, the high T1-slope group had a more significant change in the C2–C7 Cobb angle than the low T1-slope group, and both showed a decreasing trend. This may indicate that patients with high T1-slope may have a greater tendency of cervical tilting forward after surgery.

The changes in the balanced state of the lower cervical vertebra will inevitably lead to secondary changes in the upper cervical vertebrae. The important point is to maintain the visual field, the center of gravity of the skull, and the overall stability of the cervical vertebra by adjustments of the two parts of the cervical spine. Tang et al. [13] showed that the C0–C2 Cobb angle was increased after posterior cervical surgery, which was also observed in the present study, and the increase in the C0–C2 Cobb angle after surgery was positively correlated with the increase in SVA. When the cervical vertebrae are tilted forward after surgery, a compensatory increase in the C0–C2 Cobb angle will not lead to the excessive displacement of the cervical vertebrae, maintaining the visual field, the center of gravity of the skull, and the balance of the cervical vertebrae.

The most common complication after posterior surgery is axial symptoms, which are reported in 45–80% of the patients in literature [25–27]. A normal cervical physiological curvature has important biological significance for the human body, which maintains not only effective neck movement but also protects important cervical spinal nerves [28]. Given that the LAMP destroys the cervical bony structure and muscle–ligament complex at different degrees, LAMP results in the partial loss of function of the cervical posterior column structure in sharing and transferring the load, which accelerates the disorders of local mechanical balance. At the same time, the cervical vertebrae have a tendency of tilting forward after surgery, leading to the need for greater strength of the posterior neck to maintain the neck upright.

In the present study, patients with high $T1$ -slope before surgery had the same increase in postoperative $C0$ – $C2$ Cobb angle due to a large normal physiological lordosis. Overlarge upper cervical lordosis needs sustained contraction of the neck muscles to maintain an appropriate neck position, and muscle spasm may occur, which is an important cause of postoperative axial pain. In addition, wearing a neck brace for a long time after surgery limits the activity of the cervical vertebrae, resulting in a compensatory increase in the movement of the adjacent level decompression, which may also be the cause of axial symptoms after posterior surgery. Maeda et al. [29] reported that the maintenance of postoperative activity and of the physiological curvature of cervical vertebrae mainly depends on the roles of elastic scar tissue and muscle–ligament complex, rather than rigid structure (vertebral plate of bone fusion or non-elastic scar tissue, etc.). Cervical function exercise at the early stage after surgery does not aggravate nerve injury and affect the surgical effect. Therefore, it is inadvisable to promote the recovery of neurological function by reducing and limiting normal cervical activities. Thus, not only the posterior muscle–ligament complex should be protected during surgery in order to reduce injury and relieve the overextension of the upper cervical vertebrae, but also the early removal of a neck brace and functional exercise are important factors after the stabilization of internal fixator [30–32].

When the forward movement of the center of gravity of the head exceeds the adjustment range of the body to maintain the balance state with minimum energy consumption, the patient will experience a decline in the quality of life but some recovery of nerve function [33]. Any single imaging parameter of cervical spine dysplasia cannot be used as an indicator to evaluate the balance of cervical spine dysplasia. To achieve postoperative sagittal balance and in order to maintain the head and neck upright and level, the neck muscles will strengthen their contraction, become tired, even twitch, leading to muscle stiffness, fatigue, and neck pain, which will affect the patient's neck function and quality of life. In this study, the JOA score increased significantly, suggesting that the spinal canal enlargement allowed the spinal cord to take back its proper position, relieving spinal cord compression in patients with spinal cord function recovery. The increase of the $C2$ – $C7$ SVA (forward) is not enough to have a significant effect on postoperative nerve function. Therefore, $C2$ – $C7$ SVA may be associated with preoperative neurological function evaluation in patients. This study has several limitations. First, the sample size is small and from a single center. Although the patients operated over 4 years were included according to strict inclusion and exclusion criteria, relevant data could not be obtained from all patients. Second, posterior cervical open-door surgery can lead to axial symptoms. The elderly patients were predominant, and they often have less tolerance for pain.

Therefore, postoperative pain may be overestimated. Third, only the cervical spine was considered, and future studies should examine the whole spine. Finally, because of the retrospective nature of the study, only the data contained in the medical charts could be analyzed.

In conclusion, LAMP improved the cervical sagittal balance. The cervical vertebrae show a tendency of tilting forward, suggesting that overextension of the upper cervical vertebra might be used to maintain the center of gravity of the skull and horizontal vision, therefore maintaining a normal center of gravity of the skull and horizontal vision. Patients with low $T1$ -slope before surgery have less pain two years after the operation.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no competing interests.

Ethical approval This study was approved by the ethics committee of Shanxi Da Hospital.

Informed consent Informed consent was waived due to the retrospective nature of the study.

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