Feasibility study on posterior laminar screw fixation techniques in the axis

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【Abstract】Objective: To get morphologic parameters of Chinese adults through observation and measurement on axial laminas, to evaluate the feasibility of placing axial laminar screws and to introduce the technique.

Methods: Relative parameters of 28 sets of fresh Chinese adults' axial specimens, including distance from the superior and inferior entry points of axial laminar screws to the superior margins of axial laminas, superior, middle, inferior thickness and height of the axial laminas, length and angle of the axial laminar screw trajectories, distance from the entry points of axial laminar screws to the transverse foramen and central points of the inferior articular process, were measured with a digital caliper and a goniometer. Data were statistically analyzed.

Results: Averagely, distance from the superior and inferior entry points of axial laminar screws to the superior margins of axial laminas was 5 mm and 9 mm, superior, middle, inferior thickness and the height of the axial laminas were 3.2 mm, 6.7 mm, 5.5 mm and 12.8 mm respectively, and the length of the superior and inferior axial laminar screw trajectories was 26.2 mm and 25.5 mm, respectively.

Conclusions: It is feasible and reliable to apply posterior laminar screw fixation techniques to the axes of Chinese adults. Also the C_2 laminar screw fixation technique can be taken as a supplementary to conventional posterior screw fixations of C_2.

Key words: ***Anatomy; Axis; Bone screws; Cervical vertebrae***

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Pedicle screws are widely used in posterior screw fixation of the axis. However, due to anatomic structure variability, 20% to 27.5% of axis vertebrae have C_2 pedicles<5 mm in width, which makes it impossible to place pedicle screws or increases the risk of vertebral artery injury.[1] Recently, C_2 crossing laminar screws are described as an alternative for rigid fixation of the axis and have been successfully used by Wright[2] in cases of craniocervical and atlantoaxial fixation as well as for incorporation of C_2 into sub-axial fixations. This technique has little anatomic limitations and is suitable for most individuals, but the risk of laminar screws' breaking into the spinal canal still exits. The purposes of our study are to measure relative data of axial laminas and to evaluate the feasibility of placing axial laminar screws.

METHODS

Cadaveric study

Spines of 28 adult fresh human cadavers, including 18 males and 10 females, were studied. Specimens were obtained from the Anatomy Department of Ningbo University. All of the 28 specimens were Han people with the mean age of 52 years (range, 32-66 years). They were all inspected to ensure that the vertebrae were intact and free from osteophytes or metastatic tumors before measurement. The specimens were stored at -20°C until dissected. Attached soft tissues were removed after thawing. Linear measurements were made directly with an electronic caliper of 0.01-mm accuracy and angles were measured with a coherency conimeter of 0.1° accuracy. For preciseness, each specimen was measured three times and the data were averaged.

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Observation and measurement of the axis

Figures 1-6 show the detailed parameters measured in this series: distance from the superior entry point of axial laminar screw to the superior margin of axial lamina (AB), distance from the inferior entry point of axial laminar screw to the superior margin of axial lamina (CD), superior, middle, inferior thickness and height of the axial lamina (Ts, Tm, Ti and H), distance from the entry point of axial lamina to the transverse foramen (D1), distance from the entry point of axial lamina to the central point of inferior articular process (D2), length of the superior, inferior laminar screw (Ls, Li), included angle between the superior, inferior laminar screw and the transverse plane (α1, α2), and included angle between the superior, inferior laminar screw and the coronal plane (β1, β2).

Statistical analysis

Data were presented as mean±standard deviation and analyzed by SPSS 11.0 sofeware. Student's *t* test was used to compare the means. Data comparison was also made in terms of sex and bilareral anatomical parametres of C_2 laminars screws. Differences with $P<0.05$ were considered statistically significant.

RESULTS

Averagely, distance from the superior entry points of axial laminar screws to the midlines of spinous process of axis and the superior margins of axial laminas was both 5 mm. Also the distance from the inferior entry points of axial laminar screws to the midlines of spinous process of axis and the superior margins of axial laminas was 5 mm and 9 mm on average. Other data of the axial laminar screws are listed in Table 1.

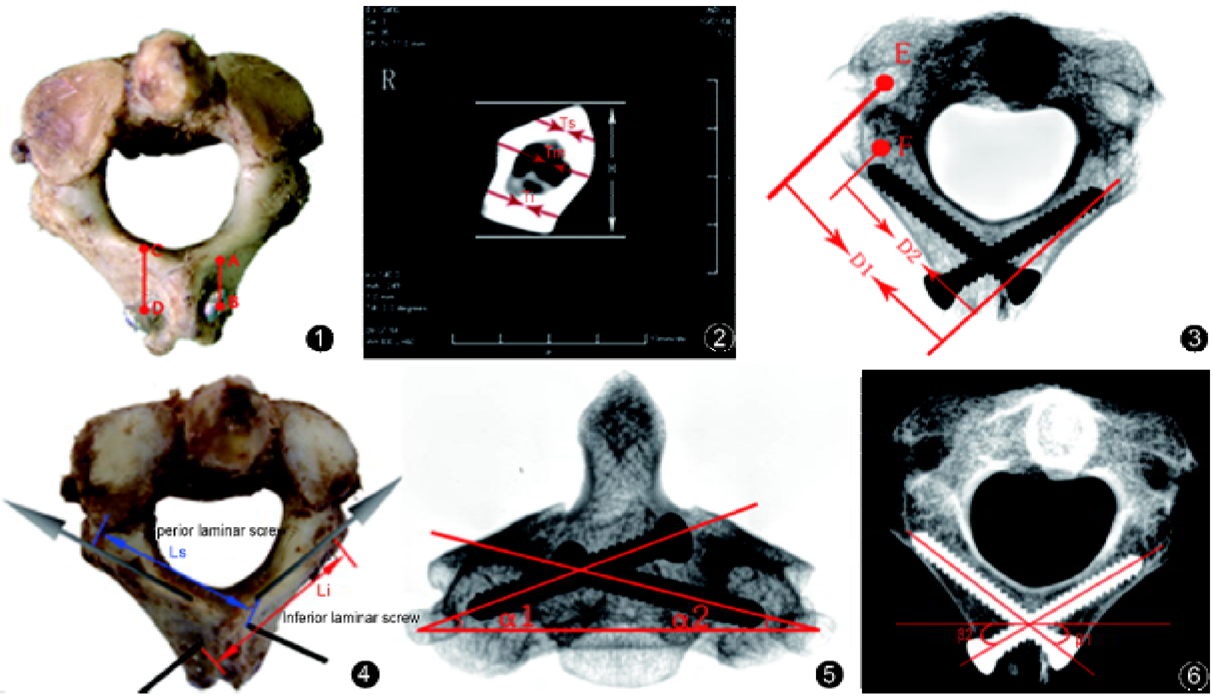

Figure 1. Distance between entry points of axial laminar screws and superior border of an axial lamina (AB: distance between entry point of superior axial laminar screw and superior border of the axial lamina, CD: distance between entry point of inferior axial laminar screw and superior border of the axial lamina). **Figure 2.** Coronal plane view on the right, middle part of an axis lamina (Ts: superior thickness of the axial lamina, Tm: middle thickness of the axial lamina, Ti: inferior thickness of the axial lamina, H: height of the axial lamina). **Figure 3.** Distance from the entry point of axial lamina screw to the transverse foramen and the central point of inferior articular process (D1: distance from the entry point to the transverse foramen, D2: distance from the entry point to the central point of inferior articular process). **Figure 4.** Ls: length of the superior laminar screw, Li: length of the inferior laminar screw. **Figure 5.** included angles between laminar screws and the transverse plane (α1: included angle between the superior laminar screw and the transverse plane, α2: included angle between the inferior laminar screw and the transverse plane). **Figure 6.** included angles between laminar screws and the coronal plane (β1: included angle between the superior laminar screw and the coronal plane, β2: included angle between the inferior laminar screw and the coronal plane).

Table 1. Anatomical parameters and detailed data of C_2 laminar screws ($\bar{x} \pm s$, n=28)

Parameters	Male		Female		Incorporation (range)
	Left (range)	Right (range)	Left (range)	Right (range)	
Ls (mm)	26.2±1.3 (23.2-29.4)	26.1±1.7 (23.5-29.1)	26.2±1.7 (23.2-29.1)	26.1±1.2 (23.0-28.9)	26.2±1.5 (23.0-29.4)
Li (mm)	25.8±1.4 (22.8-28.9)	25.7±1.5 (22.8-28.9)	25.2±1.6 (22.1-27.8)	25.1±1.3 (22.1-27.9)	25.5±1.5 (22.1-28.9)
Ts (mm)	3.2±1.3 (2.6-5.4)	3.3±1.6 (2.5-6.1)	3.2±1.9 (2.4-5.6)	2.9±1.1 (2.3-6.0)	3.2±1.5 (2.4-6.1)
Tm (mm)	6.9±1.3 (5.0-9.8)	6.8±1.3 (4.3-9.4)	6.4±1.7 (4.5-9.7)	6.5±1.5 (4.9-9.2)	6.7±1.5 (4.3-9.8)
Ti (mm)	5.8±1.4 (3.2-7.6)	5.5±1.7 (3.7-7.9)	5.3±1.7 (3.1-7.4)	5.2±1.3 (3.1-7.3)	5.5±1.5 (3.1-7.9)
H (mm)	12.9±1.5 (10.5-15.0)	13.1±1.1 (10.3-15.2)	12.4±1.3 (10.0-14.8)	12.7±1.4 (10.0-14.2)	12.8±1.3 (10.0-15.2)
D1 (mm)	32.7±1.3 (27.3-39.7)	32.5±1.2 (27.6-39.9)	31.9±1.2 (27.1-38.7)	31.5±1.4 (27.2-38.8)	32.2±1.3 (27.1-39.9)
D2 (mm)	28.7±1.4 (24.4-35.3)	28.7±1.2 (25.1-35.4)	28.2±1.2 (24.6-35.1)	28.1±1.3 (24.2-35.2)	28.4±1.3 (24.2-35.4)
α 1 (°)	7.3±2.8 (4.5-10.5)	7.5±2.2 (5.0-10.0)	7.0±2.7 (4.5-9.5)	7.2±2.3 (4.5-9.0)	7.3±2.5 (4.5-10.5)
α 2 (°)	-2.3±4.3 (-3.0-5.5)	-2.1±4.7 (-6.0-6.5)	-1.9±4.1 (-5.0-4.0)	-2.2±4.5 (-4.0-5.0)	-2.1±4.4 (-3.0-6.5)
β 1 (°)	25.6±3.7 (20.5-32.0)	26.2±3.4 (21.0-31.0)	25.5±3.3 (20.0-31.0)	25.3±3.6 (20.5-30.0)	25.6±3.5 (20.0-32.0)
β 2 (°)	30.4±3.6 (22.5-34.5)	30.5±3.3 (23.0-35.0)	29.8±3.8 (22.0-33.5)	30.3±3.2 (22.0-33.0)	30.3±3.5 (22.0-35.0)

There were no significant differences in terms of sex and bilateral parameters (t=1.54, P>0.05 and t=1.70, P>0.05). Ls: length of superior laminar screws; Li: length of inferior laminar screws; Ts: superior thickness of axial laminas; Tm: middle thickness of axial laminas; Ti: inferior thickness of axial laminas; H: height of axial laminas; D1: distance from the entry points of axial laminas to the transverse foramen; D2: distance from the entry points of axial laminas to the central points of inferior articular process; α 1: included angles between superior laminar screws and the transverse plane; α 2: included angles between inferior laminar screws and the transverse plane; β 1: included angles between superior laminar screws and the coronal plane; β 2: included angles between inferior laminar screws and the coronal plane.

DISCUSSION

Definition of C_2 laminar screw fixation

C_2 laminar screw fixation with bilateral, crossing C_2 laminar screws was initially described as a method for rigid fixation of the axis by Wright.[2] The entry point of the axial laminar screw was at the junction of C_2 spinous process and the lamina. Zhang et al[3] considered that the entry points of laminar screws were at the junction of C_2 spinous process root and middle/inferior 1/3 of the lamina, respectively. Taking the entry points of axial laminar screws and the superior border of axis laminas as location markers, Ma et al[4] defined screws as superior laminar screws and inferior laminar screws.

Feasibility study of the C_2 laminar screw fixation technique

C_2 pedicle screws could provide very rigid fixation and promise high fusion rates in atlantoaxial fixation as well as for incorporation of C_2 into sub-axial fixations.[5,6] However, C_2 pedicle screw placement is still technically challenging with the risk of vertebral artery, spinal cord and nerve root injury. Cadaveric studies of C_2 pedicles have shown a high rate of violation of the foramen transversarium during attempted pedicle screw placement. Smaller C_2 pedicles or medial localization of the vertebral artery may preclude safe C_2 pedicle screw placement in some patients.[7] A survey of Wright et al[8] who placed C_2 pedicle screws in axis revealed a 2.4% incidence of proven vertebral artery injury and a 1.7% suspected, but unproven, incidence of vascular disruption. Furthermore, injury to the vertebral artery has been identified in 8.2% of cases in Madawi et al's[9] research. Complications like neurovascular injury following pedicle screw and lateral mass screw fixation have also been reported.[10,11] For these reasons, a technique using crossing screws placed directly into the lamina of C_2, instead of traditional posterior screw fixations, was initially described by Wright.[2] One major advantage of this technique is the removal of risks to the vertebral artery during C_2 screw placement as screws remain intraosseous completely in the posterior elements. Because all relevant structures are directly visualized during C_2 lamina screw placement, intra-operative navigation is unnecessary.

The C_2 lamina and spinous process are predictably large and forceful with the internal surface of C_2 lamina perpendicular to the transverse plane, thus making the bilateral, crossing C_2 laminar screw fixation applicable to a large percentage of patients requiring C_2 fixation. As a supplementary of posterior screw fixation techniques of axis, C_2 laminar screws were initially used and illustrated by Wright[2] during his experience in treating 10 patients and they have been applied recently. The entry point of axial laminar screw was at the junction of C_2 spinous process and lamina, and bilateral, crossing C_2 laminar screws were applied in this technique. One potential drawback of this technique would be unrecognized ventral laminar screws' breaking into the spinal canal, although serious complications did not occur in the author's experiment. According to our measurement, the superior, middle, inferior thickness and height of the axial laminas were 3.2 mm, 6.7 mm, 5.5 mm and 12.8 mm, respectively. Therefore, anatomic data of these axial laminas revealed a permission of two 3.5-mm bilateral, crossing C_2 laminar screws and also suggested that C_2 laminar screws were generally applicable to Chinese.[11]

In this study, the distance from superior entry points of axial laminar screws to the midlines of spinous process of axis was 5 mm, and also 5 mm to the superior margins of axial laminas. The distance from the inferior entry points of axial laminar screws to the midlines of spinous process of axis and the superior margins of axial laminas was 5 mm and 9 mm, respectively. The inferior entry points of axial laminar screws were on the contralateral side of the superior entry points of axial laminar screws, which avoided touch between two screws at the entry point, iatrogenic fractures and stress fractures at the spinous process of axis, especially when applying 4.0-mm screws. The entry point of axial laminar screw was at the junction of C_2 spinous process and lamina, and went out from the contralateral central point of the inferior articular process to constructed the bilateral, crossing C_2 laminar screw fixation. The trajectory of C_2 laminar screw placement went through the middle and inferior parts of axial laminas that were wilder, thus resulting in little risk of injury to the neural and vascular structures as long as the implants remained intraosseous. Nakanishi et al's[13] research indicated that the diameters of axial laminas varied in individuals obviously from 2.9 mm to 7.0 mm. Measurements of cadaveric specimens by Cassinelli et al[14] showed that the average thickness of axial laminas was 5.77 mm±1.31 mm with 70.6% and 92.6% of them ⩾5mm and ⩾4.0mm, respectively, the included angles between the spinous process and axial laminas was 48.59°±5.42°, and the length of axial laminas was 2.46 cm±0.23 cm on average with 99%, 45.2% and 1.9% of them=2.0 cm, 2.5 cm and 3.0 cm, respectively. Data showed significant differences between sexes but no obvious differences in terms of nation, height or weight.

Polyaxial screws (4.0 mm×3.0 mm) were safely used in the bilateral, crossing C_2 laminar screws fixation by Wright,[2] which may be related to the bulky axes of foreigners. In fact, according to the data of this study, the C_2 lamina of Chinese can also accommodate 4.0-mm laminar screws that could provide more pullout strength than those in smaller diameters. Interestingly, only a few proportions of axes with small pedicles were accompanied by thin axis laminas. This phenomenon suggested that there is no obvious correlation between the width and thickness of axis laminas.[3] In our measurement, the distance between the entry points of axial laminar screws and the transverse foramen averaged 32.2 mm, ranging from 27.1 mm to 39.9 mm, while the distance between the entry points of axial laminar screws and the central points of inferior articular process averaged 28.4 mm with a range of 24.2-35.4 mm. These data indicated that axial laminar screws with the length of 24-27 mm were safe in fixation. The distance between the exit points of axial laminar screws and the transverse foramen averaged 3.8 mm. This could preclude the risk of vertebral artery injury caused by laminar screws. After the entry point of an axial laminar screws was confirmed in the fixation, included angles between the superior laminar screws and the transverse plane ($\alpha 1$), the superior laminar screw and the coronal plane ($\beta 1$) averaged 25.6° and 7.3° respectively, while included angles between the inferior laminar screw and the transverse plane ($\alpha 2$), the inferior laminar screw and the coronal plane ($\beta 2$) averaged 30.3° and 2.1° respectively. Moreover, trajectories of C_2 laminar screw placement must be parallel to the upper and inferior margins of laminas to prevent screws' breaking either through the dorsal surface of laminas or into the spinal canal.

Gorek et al[15] chose the intralaminar screw technique in atlantoaxial fixation, which was safe as well as biomechanically strong with pedicle screws. Biomechanically, this technique is comparable to posterior transarticular and C_1 lateral mass-C_2 pedicle screw techniques with cable fixation in flexion-extension and axial rotation, although not as stiff as in resisting lateral bending.[15,16] Some studies recently compared C_1 lateral mass-C_2 pedicle screw technique and C_1 lateral mass-C_2 intralaminar screw technique and found that the two techniques provided equivalent stability to the C_1 to C_2 complex.[15,16] So it is anatomically and biomechanically feasible and reliable to perform laminar screw fixation of the axis. C_2 laminar screw fixation technique could be used as a supplementary for conventional posterior screw fixation techniques of C_2. Matsubara et al[17] selected C_2 laminar screws in atlantoaxial fixation for patients with unilateral occlusion of the vertebral artery and constructed stability without incurring intraoperative or postoperative complications. They advocated that patients with unilateral occlusion or asymmetry of the vertebral artery were good candidates for this new technique, even if the pedicle was sufficient for pedicle screwing. A literature review has revealed that the incidence of asymmetry or hypoplasia of the vertebral artery is around 15%,[18] and damage to the dominant artery in such cases results in brainstem ischemia, with 75%-86% fatality rate reported.[19] Strong fixation is meaningless if a lethal complication occurs. To improve the operation, it is important to evaluate precisely the vertebral artery condition preoperatively besides contrast CT of the pedicle. Michael[20] reported that C_2 laminar screw's breaking into the spinal canal occurred in one case (thirty in total) although this injury was asymptomatic, and internal fixations were fractured in two cases.

Strategy of C_2 laminar screws in clinical application

Who are the best candidates for laminar screw fixation in clinic? We believed that patients with unilateral occlusion or asymmetry of the vertebral artery were good candidates for this new technique, even if the pedicle was sufficient for pedicle screwing. Reference to the literature,[17,21] we conclude that: (1) The entry points of laminar screws are at the junction of C_2 spinous process and laminas. The trajectories go through the cancellous bone of contralateral laminas and out from the contralateral central point of the inferior articular process with laminar screws completely remained intraosseous of C_2 laminas and only the posterior column of axis fixed. Therefore, pedicle screws are the best choice of axis fixation for patients with abnormal vertebral arteries but without pedicle anatomic limitations. (2) Lateral mass screws are suitable for axis fixation with pedicle isthmuses 3.5-5.0 mm in width while laminar screws are suitable for that with pedicle isthmuses<3.5 mm. (3) Under the condition when the entry point of laminar screw is near the midline of axis and far from the entry points of superior and inferior screws on coronal plane, which is difficult to place connective bar to fix more than three segments, it is better to use polyaxial screws in C_2 laminar screws fixation, but has a disadvantage of high expenditure. (4) For obvious asymmetric vertebral arteries or those with hypoplasia even unilateral occlusion, it is safer to apply C_2 laminar screw fixation. (5) It should be cautious to perform C_2 laminar screw fixation in children because of their small axis pedicles. Furthermore, surgeons should take their skills and patients' condition into consideration to choose the best fixation technique.

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