

Morphometric analysis of the seventh cervical vertebra for pedicle screw insertion

Wensheng Liao, Liangbing Guo, Heng Bao, Limin Wang

ABSTRACT

Background: Anatomy of the pedicles of the seventh cervical vertebra (C7) at the cervicothoracic junction is different from other cervical vertebrae. Fixation of C7 is required during cervical vertebra and upper thoracic injuries in clinical practice. However, the typical pedicle screw insertion methods may have problems in clinical practice based on the anatomical features of C7. This study is to explore a new pedicle screw insertion technique for C7 and to provide anatomical and radiographic basis for clinical application.

Materials and Methods: C7 vertebral specimens from six human cadavers were observed for the relative position between the posterior bony landmark and the pedicle projection. Computed tomography (CT) was performed for 30 patients with cervical spondylosis (26–61 years old, mean age was 42.3 years old). The CT scan data were processed by Mimics 8.1 software for associated parameter measurement. Appropriate screw entry points (Eps) and insertion angles were selected. A total of 12 pedicle screws were inserted and then observed. The six specimens were observed after inserting the screw using this method. The junction site of the middle 1/3 and outer 1/3 segment of line G [The junction between point A (the intersection point of the superior margin of the lamina of C7 and the medial margin of the superior articular process) and point B (the intersection point of the lateral margin of the inferior articular process and the transverse process)] was taken as the Ep. The screw insertion direction parallel horizontally to the upper terminal lamina of C7 and the sagittal angle was between 35° and 45°.

Results: Gross and imaging observations revealed that pedicle projection was on the line (line G) between point A (the intersection point of the superior margin of the lamina of C7 and the medial margin of the superior articular process) and point B (the intersection point of the lateral margin of the inferior articular process and the transverse process) and located at the middle 1/3 and outer 1/3 segments of the line (point L[also it is the screw entry points (Eps)]). No significant difference in the measurements on the left and right sides were observed ($P > 0.05$). No penetration of the 12 screws through pedicle was observed.

Conclusion: The junction site of the middle 1/3 and outer 1/3 segments of line G are the projection points of C7 pedicles on the lateral mass. The junction site anatomical position was simply and easy to be controlled during surgery, simultaneously avoided uncertainty of other methods. This study provides a new method for determining an Ep for C7 pedicle screw insertion.

Key words: Cervical pedicle, morphometric analysis, seventh cervical vertebra

MeSH terms: Cervical vertebra, bone screw, cadaver, dissection

INTRODUCTION

Posterior immobilization of the seventh cervical vertebra (C7) is often necessary for patients with cervical and upper thoracic injuries in clinical

practice. C7 is the transitional vertebra from cervical to thoracic vertebrae. It possesses unique characteristics when compared with other cervical vertebrae. First, it has a relatively thinner lateral mass.^{1,2} For this reason, lateral mass screw fixation frequently fails due to a short screw track and poor pullout forces.³ Second, it has relatively large pedicles (in diameter).⁴ For this reason, C7 pedicle screw fixation is feasible. Third, the cervical foramina of C7 have no vertebral arteries to go through.^{5,6} For this reason, C7 pedicle screw fixation has a low incidence of vertebral artery injuries and is therefore highly safe. Studies have shown that posterior cervical pedicle screws have more satisfactory mechanical stability than lateral mass screws.⁷⁻⁹ Therefore, for C7, posterior pedicle screw fixation should be the most appropriate mode.¹⁰ However, the unique anatomic characteristics of C7 entail difficulty in the use of Abumi's *et al.* method¹¹ for C7 pedicle screw fixation. The development of imaging and navigation technology

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relatively improves the safety of this technique.¹²⁻¹⁵ The technique using bony landmarks as screw entry points (Eps) remains the most extensively used, relatively safe method for cervical posterior fixation.¹⁶⁻¹⁸ Therefore, the exploration of the anatomic characteristics of C7 and the search for C7 pedicle insertion methods are necessary.

In this study, we observe the distributional characteristics of the projective points of C7 pedicles on the surface of the lateral mass and analyze the relationships of these points with their peripheral characteristic anatomic structures. The aim of this study is to find a new Ep (located at the middle 1/3 and outer 1/3 segments of the G line) localizing method.

MATERIALS AND METHODS

Six C7 specimens were supplied by the department of anatomy of basic research. Their morphology, extending directions and projection on lateral mass were observed.

The computed tomography (64 slice multidetector CT; Lightspeed VCT; GE, USA) data of 30 adult patients with cervical spondylosis were collected from the CT room of the First Affiliated Hospital. The mean age was 42.3 years (range 26-61 years). Three-dimensional reconstruction was performed. There were equal number of males and females. Those with cervical spine fracture dislocation, tumors, tuberculosis, and noticeable degeneration malformation were excluded from the study. Written informed consents for the study using image data were obtained from all patients. This study was conducted in accordance with the declaration of Helsinki and approved by the Ethics Committee of the First Affiliated Hospital of University.

Three-dimensional computed tomography simulation reconstruction for C7 screw entry point localization

The patient was placed in a supine position. High-resolution CT (in submillimeter) scanning was performed, with parameters as follows: Tube tension, 120 kV; tube current, 300 mA; time per round of rotation, 0.5 s; and slice thickness, 0.625 mm. All data were recorded on a CD disc and then introduced into Mimics 8.1 software (Materialise company, Shanghai, China). The bone tissue density window was selected for numerical value measurement. The soft tissue density window was selected for three-dimensional reconstruction using threshold (300 Hu) segmentation. Based on the three-dimensional model and the bi-dimensional images of the coronal, sagittal and horizontal planes of C7, an appropriate cylinder was constructed to simulate the insertion of pedicle screw into the C7 pedicle. The axis of the cylinder was adjusted to overlap with that of the pedicle. A projection circle was generated on the lateral mass in the C7 three-dimensional image and this circle was the Ep for C7 pedicle screw internal fixation [Figure 1].

Anatomic parameter measurement of the C7 pedicle screw entry point

Based on observations, an anatomic landmark line (G) was drawn between two points: Point A was the intersection point of the superior margin of the lamina of C7 and the medial margin of the superior articular process and point B was that of the lateral margin of the inferior articular process and the transverse process [Figure 2].

The anatomic data associated with the Ep and line G were measured on the three-dimensional image, including the length of line G (Lg), the distance between the Ep and point A (La), the distance between the Ep and point B (Lb), the distance between the Ep and line G (DG; a negative value was assigned when the Ep was below line G, a positive value was assigned when the Ep was above line G, and 0 was assigned when the Ep was on line G), and the distance between the Ep and the inferior margin of the upper articular process (DH). The ratio of La/Lb was calculated [Figure 1].

C7 pedicle associated imaging parameter measurement

Imaging parameters were measured, including the outside diameter of C7 pedicle, inner diameter of C7 pedicle, thickness of the cortical bone of the inner wall of the C7 pedicle (T), axial length of the C7 pedicle (L), total length of the bony tract along the C7 pedicle axis (TL), the vertical distance between the C7 pedicle Ep and the median line (LD), and included the angle between the long axis and sagittal plane of the C7 pedicle (β). Pedicle outer height was the shortest distance between the upper and lower outer margins of the cortical bone on the cross section at the narrowest pedicle site. Pedicle outer width was the shortest distance between the interior and exterior margins of the cortical bone on the cross-section at the narrowest pedicle site. Pedicle inner height was the shortest

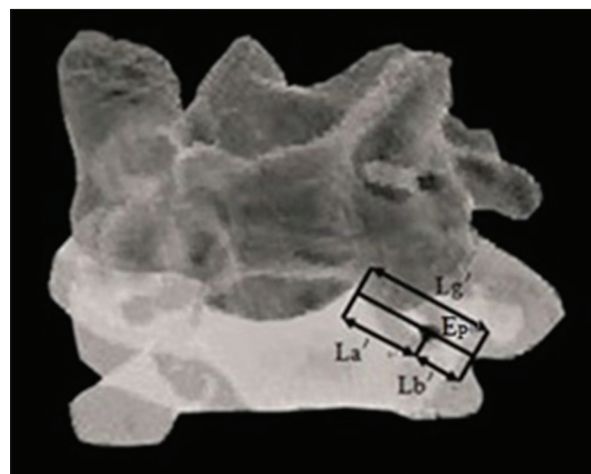


Figure 1: CT Three dimensional simulation image showing parameter measurement of the position relation between line G and the entry point using C7 vertebra

distance between the upper and lower outer margins of the cortical bone on the cross-section at the narrowest pedicle site. Pedicle inner width was the shortest distance between the interior and exterior margins of the cortical bone on the cross-section at the narrowest pedicle site. L was the distance from the Ep of the pedicle axis on the back cortical surface of the lateral mass to the meeting point of the pedicle and vertebra. TL was the distance between the Ep of the pedicle axis on the back cortical surface of the lateral mass and its Ep on the anterior margin of the vertebra [Figure 3]. LD was the length of the vertical line of the C7 sagittal axis through Ep.

C7 pedicle screw insertion

Based on the obtained anatomic and imaging observations, as well as the measured data, appropriate screws were selected for insertion. The specimen was inserted screw using the novel method (The junction site of the middle 1/3 and outer 1/3 segment of line G was taken as the Ep. The screw insertion direction parallel horizontally to the upper terminal lamina of C7 and the sagittal angle was between 35° and 45°). After insertion, the screws were observed [Figure 4].

Statistical analysis

Data were presented as mean \pm standard deviation of the mean ($\bar{x} \pm s$) and analyzed using SPSS 13.0 software (SPSS Inc., Chicago, United States). *t*-test ($\alpha = 0.05$) were used to compare the measured indices on the left and right sides. Differences of $P < 0.05$ were considered as statistically significant.

RESULTS

Anatomic parameter measurements of the position relations between line LG and the entry point

The mean DG values on the left and right sides were 0.15 and 0.12 mm, respectively. Considering the diameters of the pedicles and the screw, it is reasonable to assume that the Ep was basically located on line G. The mean DH values on both the left and right sides were approximately 2 mm, which indicates that the Ep was 2 mm away from the inferior margin of the upper articular process. The La/Lb ratios on the left and right sides were 1.99 and 2.00, which indicates that the Ep was located at the junction site of the middle 1/3 and outer 1/3 segment of line G. The results are summarized in Table 1.

C7 pedicle associated diameter lines and imaging parameter measurements

As shown in Tables 2 and 3, the C7 pedicle had a larger inner diameter, which allowed a screw with a diameter of 3.55 mm to be inserted. Under ideal condition, the TL could exceed 30 mm. The mean β value was 41.1°.



Figure 2: Specimen of C7 vertebra showing line G and the entry point (the junction site of the middle and outer 1/3 segments of line G) for C7 vertebra

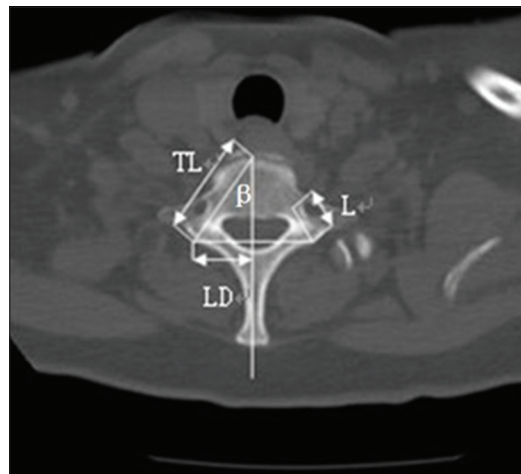


Figure 3: CT scan axial image showing measurement of the C7 and pedicle associated diameters and angle



Figure 4: Specimen of C7 vertebra showing pedicle screw insertion

C7 pedicle screw insertion

The six C7 bony specimens were taken. The junction site of the middle 1/3 and outer 1/3 segment of line G was taken as

Table 1: Imaging parameter measurements of line G and the Ep of C7 ($\bar{x}\pm s$; mm)

C7	Lg	La	Lb	DG	DH	La/Lb
Left side	11.07±0.28	7.47±0.16	3.74±0.28	0.15±0.01	2.04±0.16	1.99
Right side	11.12±0.27	7.50±0.13	3.75±0.23	0.12±0.01	1.96±0.11	2.00
T value	0.152	0.923	0.082	0.150	1.633	
P value	>0.05	>0.05	>0.05	>0.05	>0.05	

EP=Entry point

Table 2: Imaging parameter measurements of the inner and outer diameters of C7 pedicles ($\bar{x}\pm s$; mm)

Measurement index	OPW	IPW	OPH	IPH
Male	6.56±0.36	3.23±0.31	7.21±0.35	4.13±0.28
Female	6.44±0.34	3.09±0.31	7.18±0.35	4.09±0.26
Mean	6.51±0.35	3.13±0.28	7.20±0.33	4.11±0.27
T value	1.622	1.264	1.234	0.103
P value	>0.05	>0.05	>0.05	>0.05

OPW=Outer pedicle width, IPW=Inner pedicle width, OPH=Outer pedicle height, IPH=Inner pedicle height

Table 3: Imaging parameter measurements of C7 pedicle associated diameter lines and angles ($\bar{x}\pm s$)

Vertebra	T (mm)	L (mm)	TL (mm)	LD (mm)	β (°)
Male	1.72±0.13	16.47±1.85	33.22±2.01	22.45±2.20	41.3±2.1
Female	1.68±0.12	15.27±2.12	32.55±1.90	21.51±1.72	40.8±1.6
Mean	1.73±0.13	15.85±1.81	32.89±1.76	21.98±2.02	41.1±1.9
T value	1.569	1.620	1.388	1.417	1.468
P value	>0.05	>0.05	>0.05	>0.05	>0.05

the Ep. The screw insertion direction parallel horizontally to the upper terminal lamina of C7 and the sagittal angle was between 35° and 45°. Based on the measurements obtained in this study, pedicle screws with a diameter of 3.5 mm and a length of 24 mm were selected for insertion. A total of 12 screws were used. No penetration of the screws through the pedicle cortical bone was observed.

DISCUSSION

Lateral mass screw fixation and pedicle screw fixation are the two commonly-used fixation methods for lower cervical spine. Compared with former, the latter has a higher fixation intensity,⁷ which enables to achieve fixation by only immobilizing a short segment. However, cervical pedicles have a complicated anatomy structures. They neighbour internally on the spinal cord and externally on the vertebral arteries (with the exception of C7). They have nerve roots to go through. Moreover, they are thin, which causes difficulty in screw inserting and increases the risk of injuries to the important surrounding organs after screw insertion. Therefore, accurate screw insertion is of critical significance.

For diseases occurring at the cervicothoracic junction, such as fracture dislocation, tumors, tuberculosis and malformation, C7 fixation is often necessary. C7 is the

transitional vertebra from cervical vertebrae to thoracic vertebrae. Its lateral mass is thinner and longer compared with those of the third and sixth cervical vertebrae.^{1,2} Therefore, C7 lateral mass screw fixation is less firm and reliable than that of other cervical vertebrae and screws for the fixation use are more likely to loosen, from the perspective of mechanics.³ Meanwhile, about 99% of C7s have no vertebral arteries to pass through the cervical foramina,^{5,6} and compared with the third and sixth cervical vertebrae, C7 has a thick pedicle. These characteristics of C7 ensure that the pedicle technique is safer and more feasible for C7. Therefore, the pedicle screw technique is a method of choice for C7 posterior fixation.

Abumi *et al.* have reported the method for transpedicular screw insertion for the first time in 1994.¹¹ The transpedicular (C3–C7) Ep is located slightly below the inferior margin of the inferior articular process of the upper vertebra and 5 mm inwards from the outer margin of the lateral mass. The angle between the screw and the sagittal plane of the vertebra is about 25–45°, which is determined by the measurement on the CT image. For C4, the screw should incline towards the head; for C3, more inclination should be done, and for C5–C7, the screw should be parallel to the upper terminal lamina. Ebraheim *et al.* (1996) proposed laminectomy and pedicle probing.¹⁹ According to their method, the vertebral lamina of the segment needing fixation is partially resected to directly probe or expose the pedicle and then a pedicle screw is safely inserted under direct vision. The Ep is determined as follows. The horizontal line between the left and right inferior articular processes of the upper vertebra and an ordinate between the outer margins of the lateral masses of the adjacent vertebrae were respectively drawn. The Ep is located 1.6–2.6 mm below the horizontal line and 4.5–6.4 mm inward from the ordinate. The included angle between the horizontal planes and the surface of the lateral mass falls between 90° and 100° and that between the sagittal planes and the surface of the lateral mass between 53° and 94°.

However, when the same pedicle screw insertion technique for C3–C6 is applied for C7, difficulties will arise in clinical practice. Although Abumi *et al.*¹¹ and Ebraheim *et al.*¹⁹ treated C3–C7 as a whole and explored the general anatomic law of the lower cervical pedicles, they failed to differentiate the Eps for C3–C7. Shin *et al.* measured

the image data of 25 cadavers' fresh cervical vertebrae specimens and proved the special characteristics of C7 pedicles.²⁰ They pointed out that the characteristics of the pedicles of different cervical vertebrae should be considered during pedicle screw insertion. Bearing the special anatomic characteristics of C7, Barrey *et al.* conducted a study on the Ep for C7 pedicle screw insertion.² According to them, the Ep should be chosen at the intersection site of two lines: The vertical line goes through the middle points of the zygapophyseal joints of C6 and C7 and the horizontal line goes through the site 1 mm below the middle point of the transverse process of C7. Screw direction should incline inward by 30–50° and downward by 5° taking the lower terminal lamina of C7 as a reference. Although Barry's method is based on the anatomic characteristics of C7 and therefore has better feasibility, the accurate determination of the vertical line through the middle points of the zygapophyseal joints of C6 and C7 may still be difficult for patients with serious zygapophyseal joint hypertrophy. Moreover, the transverse process of C7 in itself is oblique and has variations, which entails difficulty in determining its middle point. In addition, the exposure of the transverse process may increase the risks of hemorrhage and soft tissue injuries. Therefore, the exploration of the anatomic characteristics of C7 pedicles and the search for easy and accurate pedicle screw insertion method for C7 is necessary.

In this study, the observation of C7 revealed rather stable anatomic landmarks closely related with Ep, which can accurately localize the Ep of C7 pedicles. According to the concept of line G in this study, the line was equally three segments and the junction site of the middle and outer segments served as the Ep (point L). This finding was further proved by the imaging measurements in this study. In addition, points A (the intersection point of the superior margin of the lamina of C7 and the medial margin of the superior articular process) and B (the intersection point of the lateral margin of the inferior articular process and the transverse process) are easily exposed and recognized during the operation. Therefore, they serve as two relatively permanent anatomic landmarks. Taking the junction site of the middle and outer segments of the line between points A and B (line LG) as the Ep for C7 satisfies the anatomic characteristics of C7 and therefore has satisfactory feasibility and practicality. However, to successfully insert pedicle screws, screw direction is also important, apart from Ep selection. This study found that the included angle between the long axis and the median line of C7 pedicles was $41.1^\circ \pm 1.9^\circ$, which was larger than those measured using other methods in the literature.^{2,14,20,21} This inconsistency is presumably caused by different Eps, measurement errors, different investigated populations, and so on. In this study, the screw was inserted at point L and then forced on along

the axial line of the pedicles. The horizontal plane was parallel to the upper terminal lamina of C7 and formed an included angle between 35° and 45° with the median line of the pedicles. As shown in Tables 2 and 3, the C7 pedicle had a rather inner diameter, which allowed a screw with a diameter of 3.55 mm to be inserted. Under ideal condition, the TL could exceed 30 mm. The mean β value was 41.1°. The screw insertion direction parallel horizontally to the upper terminal lamina of C7 and the sagittal angle was between 35° and 45°. Based on the measurements obtained in this study, pedicle screws with a diameter of 3.5 mm and a length of 24 mm were selected for insertion. The method using the junction site to get anatomical position was simply, which was prone to be controlled during surgery. Simultaneously, compared to other methods, the method also avoided uncertainty. In the study, individualized descriptions for the junction site and screw insertion direction were designed according to fixed anatomical landmarks. The two endpoints (the point A and point B) in G line were the two local anatomy of C7. Our results showed that based on the constant existence, small variation and easy to exposure in surgery, the connecting line, G line, could be believed as the reference to confirm the screw insertion direction of C7. Collectively, compared to typical pedicle screw internal fixation methods, herein the collected anatomic markers were more simply, visual and distinguishable and the screw insertion direction was prone to be located. Traditional methods are mostly selected vertebral sagittal plane and horizontal plane as the reference plane. This anatomical positions usually are not intuitive during operation and reference objects are not easy to detect and correct. So the performer inaccurately estimate the actual position of the vertebral body, causing the failure of surgery. Simultaneously, the method could reduce the incidence of surgical complications and further improve the success rate of surgery nailing. Therefore, the method was of certain scientificness. A total of 12 pedicle screws were inserted. No penetration of the screws through pedicles was observed. This result proved that the method adopted in this study has satisfactory feasibility and repeatability. However, in order to solve the variation of the C7, we still stressed that a new pedicle screw should be inserted based on the three-dimensional reconstruction as well as individualization.

CONCLUSION

We proposed a new pedicle screw insertion method in this study, based on the special anatomic characteristics of C7 pedicles, as well as the anatomic observations and imaging measurements. The junction site (point L) of the middle 1/3 and exterior 1/3 segments of the line between the intersection site of the superior margin of the lamina of

C7 and the medial margin of the superior articular process and the intersection point of the lateral margin of the inferior articular process and the transverse process (line G) can be taken as the Ep. A screw is inserted with its horizontal plane parallel to the upper terminal lamina of C7 and a sagittal angle of 35–45°. The practicality and reliability of this method is expected to be further proved in future studies.

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