CT evaluation of upper thoracic spine for surgical application of transarticular screw placement

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Abstract

Introduction Although pedicle screw fixation has been increasingly used in the upper thoracic spine in recent years, controversies exist about the safety and complications such as nerve or vascular intrusion associated with the technique. In this study, an alternative method of transarticular screw fixation was validated.

Materials and methods Morphometric analysis was performed on computed tomography (CT) scans of the upper thoracic zygapophysial joints of C7, T1, T2 and T3 in 20 male and 20 female patients in the axial and sagittal planes. The degree of screw angulation was recorded in the sagittal and axial planes and the screw length was measured at the spinal level from C7 to T3.

Results The smallest medial–lateral diameter and anterior–posterior diameter of IAP was found at T3 in the female patients and C7 in the male patients. The screw trajectory length ranged from 14.9 to 20.5 mm in all patients. All the above measurements were significantly

different between male and female patients at all levels ($P < 0.05$). The mean value of screw trajectory angle was 19.3° – 20.1° in the axial plane and 44.3° – 45.7° in the sagittal plane. There was no statistically significant difference ($P > 0.05$) between male and female patients in the axial and sagittal angles.

Conclusion The morphometric data of C7–T3 zygapophysial joints indicate the suitable screw diameter and screw length for this technique. Transarticular screw fixation proved to be a potentially safe alternative to pedicle screw fixation in this region.

Keywords Upper thoracic spine · Internal fixation · Transarticular screw · Transfacet screw

Introduction

Surgery of the upper thoracic spine presents a challenge to orthopedic surgeons. A complicating feature of this transition is the disparate anatomy between the cervical and thoracic posterior elements. The differences in anatomy require a variety of internal fixation devices for stabilization and fusion [1]. Meanwhile, the location between the mobile cervical and the fixed thoracic vertebrae requires adequate fixation strength to bear a complex stress. So the creation of a fusion construct that both safe and biomechanically reliable is extremely important. In the subaxial cervical spine, the most common type of posterior fixation is the use of lateral mass screws coupled with a top-loading rod or plate. The large volume of the cervical lateral mass allows safe placement of this type of screws [2–4]. Laminar hooks, sublaminar and interspinous wires have been used in the upper thoracic spine. Compared with these systems, pedicle screws are increasingly applied in clinical practice

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by affording the advantage of three-column control. Considering that the rate of pedicle violation during intraoperative placement of thoracic pedicle screws is reportedly as high as 38.9%, great caution should be taken to select the patients by excluding those with narrow pedicles, great variability, or curvature [4–8].

During the past several years, transarticular screws have been used as a fusion construct at the upper cervical and lumbar spine. The use of transarticular screws offers numerous potential benefits including superior pullout strength, load-to-failure ratio, decreased risk of damage to the spinal cord, as well as easier technology [9–11]. To our knowledge, there is no transarticular screw fixation-related morphometric study in the upper thoracic spine. In this study, we evaluated the dimensions of upper thoracic zygapophysial joints and determined the proper starting point and safe screw length for this technique. We believe that the data from this study would substantially increase the spinal surgeon's understanding of the upper thoracic spine fixation.

Materials and methods

The study consisted of 40 patients (20 females and 20 males), who were selected from all patients who underwent an upper thoracic CT scan in our hospital between September 2006 and 2008. The patients were excluded on the basis of skeletal immaturity or radiographic evidence of trauma, metastatic or inflammatory disease, infection, congenital malformation, previous surgery, or deformity (i.e., kyphosis or scoliosis). The mean age of the male patients was 50 ± 13.2 years (range 34–67 years) and the mean age of the female patients was 48.9 ± 13.7 years (range 31–65 years). All patients were scanned using a CT scanner (GE LightSpeed VCT0.6). The primary images were acquired using a standard algorithm with 1.0 mm slice thickness and 0.6 mm reconstruction interval. Reconstructions were performed with Windows NT 5.0 from the CT images using the measurement tools of the workstation.

The transarticular screw fixation in our investigation differs with transfacet pedicle screw fixation. The trajectory of transfacet pedicle screw passes the facet and pedicle into the cancellous bone of the vertebrae. Our screw passes the facet and emerges from the lateral border of the vertebra instead of inserting into the vertebral body. Generally speaking, the direction of transarticular screw is laterally in the axial plane and caudally in the sagittal plane.

In the axial plane, the medial–lateral diameter of the inferior articular process (IAP) was measured at each spinal level from C7 to T3 as the largest distance from the medial to lateral outer cortex (Fig. 1). The anterior–posterior diameter of IAP was measured as the distance from the dorsal to ventral cortex just at the level of the superior

Fig. 1 IAP width (the largest distance from the medial to lateral border)

Fig. 2 IAP thickness (dorsal to ventral cortices just at the level of the superior articular process top of the next vertebra)

articular process, top of the next vertebra in the sagittal plane (Fig. 2).

A transarticular screw is simulated inserting at C7/T1, T1/T2 and T2/T3 by analyzing the CT images at these levels. In the axial plane, the screw trajectory (OA) started 2 mm lateral to the medial border of the zygapophysial joints and oriented laterally. The appropriate angularity (AOB) between the trajectory and the anatomic sagittal plane (OB) was measured (Fig. 3).

Fig. 3 Angularity (AOB) between the trajectory and the anatomic sagittal plane

Fig. 4 Angularity (COD) created by the screw trajectory and the posterior surface of IAP

Screw length was measured using sagittal reconstructions through the supero-inferior facet. The measurement was taken, starting at the midpoint of the supero-inferior joint space and terminating at the midpoint of the next pedicle (OC). The angularity of screw placing in the sagittal plane (COD) was created by this screw trajectory and the posterior surface (OD) of IAP (Fig. 4).

CT scan was performed by a radiologist who had 10 years' experience with the procedure. All the measurements in our research were performed by the same surgeon using the specified machine, who was blinded for the eligible imaging. The surgeon was familiar with the anatomy and the screw insertion techniques in upper thoracic spine. Every parameter was measured three times in one person and the mean was obtained to be the ultimate value. We used this method to minimize the deviation and make our research more reliable.

A statistical analysis of all results was performed using SPSS software (version 13.0; SPSS Inc.). Descriptive statistics including mean, standard deviation for each parameter were computed and *P* values were calculated. Significant differences ($P < 0.05$) in each measurement on gender were determined by Student's *t* test, and significant differences ($P < 0.05$) between individual spinal levels were determined by Fisher's least significant difference (LSD) test.

Results

Four linear and two angular parameters were measured in 160 vertebrae, bilaterally of C7–T3. The results showed that there was no significant difference between the right and left sides for either measurement. The data from CT image measurement are summarized in Tables 1, 2, and 3. Analysis of the male and female patients was performed separately.

Table 1 IAP width and thickness

Level	IAP width (mm)		IAP thickness (mm)	
	M	F	M	F
C7	10.1 ± 1.1	9.6 ± 1.0	7.2 ± 0.8	6.4 ± 0.9
T1	11.2 ± 1.2	10.3 ± 1.1	8.3 ± 1.0	6.9 ± 1.2
T2	10.6 ± 1.2	9.5 ± 1.3	7.8 ± 1.2	6.2 ± 1.1
T3	10.2 ± 1.3	9.3 ± 1.0	7.5 ± 1.1	6.0 ± 1.3

Values are ±standard deviation

Table 2 Screw trajectory angularity in the axial plane (AOB)

AOB (°)		
Level	M	F
C7	20.1 ± 1.3	20.2 ± 1.1
T1	19.7 ± 1.2	19.5 ± 0.9
T2	19.3 ± 0.9	19.4 ± 1.3
T3	19.4 ± 1.1	19.7 ± 1.1

Values are ±standard deviation

Table 3 Screw length and screw trajectory angularity in the sagittal plane (COD)

Level	Screw length (mm)		COD (°)	
	M	F	M	F
C7T1	17.4 ± 1.1	15.8 ± 1.3	45.2 ± 1.3	45.7 ± 1.4
T1T2	19.0 ± 1.3	17.5 ± 1.4	44.8 ± 1.4	44.6 ± 1.2
T2T3	18.3 ± 1.2	16.7 ± 1.4	44.3 ± 1.2	45.2 ± 1.2

Values are ± standard deviation

Medial–lateral and anterior–posterior diameter of IAP

The results of medial–lateral diameter and anterior–posterior diameter of IAP are shown in Table 1. The medial–lateral diameter ranged from 8.4 to 11.3 mm in females and 9.3 to 12.2 mm in males. The anterior–posterior diameter ranged from 5.5 to 7.3 mm in females and 6.4 to 9.1 mm in males. The smallest medial–lateral diameter and anterior–posterior diameter were found at T3 in females and C7 in males. The largest medial–lateral diameter and anterior–posterior diameter were found at T1 in both males and females. Statistically significant differences ($P < 0.05$) were found between males and females at all levels.

Screw trajectory length

Screw trajectory length (14.9–20.5 mm) was significantly dependent ($P < 0.05$) on gender and spinal level (Table 2). Mean screw length was greater in males at all measured levels and the greatest at T1–T2 for males (20.5 mm) and females (18.8 mm). Screw length was the shortest at T2–T3 for females (14.9 mm), and C7–T1 for males (16.7 mm).

Screw trajectory angle

The results of screw trajectory angle in axial and sagittal planes are shown in Table 3. No obvious trend was observed from the cranial to the caudal of the screw trajectory angle in sagittal plane in males and females. There was no statistically significant difference ($P > 0.05$) between males and females in the axial angle.

Discussion

The pedicle screw system has been widely used for posterior spine instrumentation over the past 20 years [12, 13]. It provides rigid three-column fixation and shows superior biomechanics to other techniques such as sublaminar hooks and wires. However, inserting pedicle screw becomes a challenging work in the presence of anatomic variance,

pedicle fracture, pedicle violation by tumor, or revision of failed pedicle screws. Transarticular screw fixation was described in 1987 by Magerl and Seeman as being biomechanically superior to the other techniques for atlantoaxial fixation. In the subsequent years, transarticular screw fixation in the lower cervical spine was attempted clinically in clinic, and some related articles were published [14, 15]. However, there is no research about the use of this transarticular technique in the proximal thoracic spine by now. We propose transarticular screw be a good alternative to pedicle screw in this region, especially when the spinous process and lamina are deficient. In this study, we provide the anatomic data of the upper thoracic zygapophysial joints by CT scans and describe the method of screw placement in detail.

Although in vivo measurement using CT images is thought to be important for placing internal implants, only a small number of CT-based anatomic studies related to the posterior zygapophysial joints were retrieved. Abdullah et al. [16] studied the morphometry of the lateral masses of C5, C6, and C7 and first analyzed the volumetric variance of the cervical lateral mass. They claimed that despite the fact that the C7 lateral mass was thinner in two-dimensional measurements than in higher cervical vertebrae, the volume of the lateral mass remained essentially the same throughout the lower cervical spine. The likely underlying reason is the increase in length of the C7 lateral mass compared to the higher levels. There is no so-called “lateral mass” in the thoracic spine and the corresponding part should be inferior articular process (IAP). Indeed, the length of the lateral mass or IAP is of less importance in inserting a transarticular screw compared to inserting a lateral mass screw. So, we select medial–lateral diameter and anterior–posterior diameter of IAP as the two measurements in our investigation, which can reflect the true volume for transarticular screw insertion. Our measurements of the medial–lateral diameter of IAP from C7 to T3 in this study showed that the largest one was at T1. Because the diameter of the screw should be appropriate for the facet joints, the smallest width is determinant of the feasibility of this technique. If the diameter of the screw is very large, articular fracture or burst may occur. In this study, the smallest one (8.4 mm) was found at T3 in the females, so a 4.0–4.5 mm screw is recommended for upper thoracic transarticular fixation. A 4.0 mm screw can be inserted at all levels and allows enough bony bridge both medially and laterally. The data of the anterior–posterior diameter show a similar trend to the medial–lateral diameter. This measurement originated from the top of SAP in the next vertebrae and covered important part of the screw trajectory. Transarticular screw fixation has been attempted at C7–T1 [1], the morphometric similarity revealed in this study indicates that screw fixation could get enough bony purchase in T1–T3.

Stemper et al. [17] measured the width of the lateral mass in the axial plane by CT and compared the safe screw length using Roy-Camille and Magerl techniques. They emphasized that excess length of the screw may cause injury to nerves or vessels by any technique. In our study, the screw length was measured at the level of C7/T1, T1/T2 and T2/T3. Correct determination of the entry point for screw insertion is a critical step in this technique. In this study, the entry point was selected 2 mm lateral to the medial border of the articular joint at the midline of the supero-inferior joint space in the dorsal face of IAP. The tip of the screw emerged below the base of the anterolateral corner of the superior articular process, lying in the “safety margin” between the vertebral body, rib head and the rib tubercle. The anatomy around this area is different with the cervical spine. The vertebral artery does not pass this region but the pleural cavity located anterior. A proper screw length could avoid the pleural from injury. A 16–18 mm screw is recommended for upper thoracic transarticular fixation. On the other hand, the screw in our study terminated at the rib and the pleural could be protected by the rib even if the screw is a little longer. Nerve tissue around the upper thoracic spine was also considered in our research. The screw runs laterally apart from the spinal cord and the screw exit just lies in the middle of the superior and inferior nerve roots. The spinal cord and the nerve root would not be penetrated if the entry point and orientation are correct. In addition, correct angulation of screw insertion in the two planes is an important matter for screw fixation. Our findings suggest that the screw trajectory angle should be preferably 20° in the transverse plane and 45° in the sagittal plane. The transarticular screw runs a way inferiorly and anterolaterally. However, significant variations exist at each level with either technique. Preoperative CT evaluation is recommended, especially in female patients. In operation, posterior surface of the facet joint is well exposed after dissection of cervical muscles. An awl is used to pierce the cortical bone of the entry point. The point is then drilled with a 3.5 mm bit. The drill operator can feel the tip of the drill penetrating the facet and the facet joint. The length of the screw is determined using a depth gauge. The facet joint is then tapped using a transarticular screw. This technique is easily performed.

Transfacet pedicle screw fixation has been studied extensively in the lumbar spine. It is considered a good alternative to pedicle screw fixation. Biomechanical studies have shown that lumbar transfacet pedicle screw is biomechanically equivalent to the pedicle screw [18, 19]. Akbay et al. [20] used the transfacet pedicle screw in the middle and lower thoracic spine to compare its experimental biomechanical result with that of standard pedicle screw. Indeed the technique of transarticular screw fixation in our investigation is different with transfacet pedicle screw fixation. The trajectory of transfacet pedicle screw passes the facet and pedicle into the cancellous bone of the vertebrae. Our screw passes the facet and emerges

from the lateral border of the vertebra instead of inserting into the vertebral body, thus greatly increasing the biomechanical reliability by puncturing four cortexes. In fact, the biomechanical comparison between pedicle screw/rod construct, transarticular screw/rod construct and transarticular screw had been finished by our team. The results showed that no significant differences were observed between the three instrumented groups. Transarticular screw and pedicle screw have statistically similar biomechanical stability in the upper thoracic spine. We presumed that the transarticular screw got an increasing biomechanical property by puncturing four cortexes. Pedicle screw provides rigid three-column fixation and shows superior biomechanics to other techniques. However, if there are obstacles for pedicle screw inserting, such as anatomy variance, pedicle fracture and lamina deficiency, transarticular screw could be a good alternative to pedicle screw in upper thoracic spine. That is why we collected the anatomic data of the upper thoracic joints by CT scans and studied the method of screw placement [21].

Kretzer et al. [5] described the translaminar screw placement in the T1 and T2 vertebrae, after this technique was used for C1–C2 fixation. Our investigation focused on the upper thoracic spine, and the transarticular screw could be a selective supplement for other technique. The anatomic data of the facet joints in upper thoracic spine were limited in number. One limitation of our study was that the sample size was not large enough to represent all the population. Furthermore, anatomic experiment in cadaver specimens does not carry out. It is important to combine imaging studies with direct visualization experiments to confirm the feasibility of our technique.

Conclusion

Transarticular screw fixation was attempted based on radiographic measures of the upper thoracic zygapophysial joints. The data indicate that a screw with a diameter of 4.0–4.5 mm and a length of 16–18 mm is preferable for this technique, and the screw should be inserted inferiorly and anterolaterally. This transarticular screw fixation technique is a good alternative to the pedicle screw fixation in particular conditions.

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Conflict of interest None.

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