Computer analysis of the safety of using three different pedicular screw insertion points in the lumbar spine in the Chinese population

Yu Hailong · Lei Wei · Ma Zhensheng · Sang Hongxun

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Abstract To help decide the best starting point for lumbar spine pedicle screw insertion in the Chinese population using three different techniques (Roy-Camille, Magerl, and Du). Three-dimensional CT reconstructions were created from 40 adult lumbar vertebral segments. Three different starting points for lumbar pedicle screw insertion were used. The direction of the pedicle screw through each hole was simulated on three-dimensional reconstructed images. Precise CT measurements were made to assess the distance from the simulated screw and the medial and lateral pedicle walls at the smallest transverse section of each pedicle. To measure a pedicle transverse section angle (TSA) lines were drawn on a CT scan in the direct axis of the pedicle, tangential to the medial, and separately lateral, walls of the pedicles at the isthmus. The angle these lines made with an anterior to posterior line, which directly bisected the mid-portion of the vertebral body was called the TSA. The greater the difference between the TSA between the medial and lateral walls provides the greatest flexibility for the insertion angle of the pedicle screw. Additionally, the distance from a line drawn in the direct central axis of the pedicle was measured from the point of exit from the pedicle to the entry point of each of three insertion techniques (Du, Magerl, and Roy-Camille), to help

understand potential risk factors. There were statistically significant differences between the distances from the entrance point to the direct pedicle axis among the three methods ($P < 0.001$). Du's insertion point was the shortest from L1 to L4. The distances measured following Magerl's technique were shortest at L5 ($P < 0.05$). There was no significant difference of the safe range of the TSA between the three methods from L1 and L2 ($P > 0.05$), but significant differences at L3, L4, and L5 ($P < 0.05$). At L3 and L4 the safe ranges of TSA using Du and Magerl's methods were significantly larger than those measured by Roy-Camille ($P < 0.05$). At L5 the safe ranges of TSA for the Magerl technique were the greatest among the three methods ($P < 0.05$). These results demonstrate that Du's method provides the safest starting point to place pedicle screws from L1 to L4, as its distance from the entrance point to the pedicle axis is the shortest and the safe range of TSA the largest of the three techniques. Magerl's technique can be safely used in the pedicles from L3 to L5, and is the safest choice at L5. Roy-Camille's technique is most applicable at L1 and L2, but has the highest risk when applied from L3 to L5.

Keywords Pedicle screw insertion · Lumbar spine · Spinal fixation · Computed tomography

Y. Hailong · L. Wei (✉) · M. Zhensheng · S. Hongxun
Department of Orthopaedics, Xijing Hospital of the Fourth Military Medical University, Xi'an 710032, People's Republic of China
e-mail: leiwei@fmmu.edu.cn

Y. Hailong
e-mail: yuhailong118@yahoo.com.cn

Introduction

Pedicle-based screw fixation techniques are widely used for stabilization and correction of spinal instability and deformities [2]. The pedicle provides the most rigid fixation point in the lumbar spine. Additionally, it is one of the safest areas to instrument because of the

surrounding cortical bone which helps protect the neural elements. However, despite their common use, safety concerns related to screw malposition have been described [4–7, 9]. Violation of the pedicle by a screw can cause injury to the neural structures along any of the four quadrants of the pedicle. When this occurs, the negative consequences of screw placement may outweigh the advantages offered by the systems.

The posterior entry point dictates the direction the screw, enters the pedicle and then the vertebral body. Different pedicle screw entry points have been described by a number of authors. Three of the most commonly employed techniques are those by Roy-Camille [14], Magerl [11], and Du [5]. The insertion point, relative to the central portion and direction of the pedicle, leads to different angles of insertion of the screws. Some may have a straight trajectory down the pedicle, and others may require steeper angles for insertion. Studies suggest that lumbar pedicle morphometric characteristics vary in different population groups [8, 12, 13, 15]. It is essential to know the differences between the methods of insertion and pedicle morphometry in different populations to allow proper choice of the best method of lumbar pedicle screw fixation. There are no reports of these assessments in the Chinese population.

The authors used three-dimensional reconstructions of computer-assisted tomograms (CT) to assess the pedicle direction relative to different entry points. Screws were simulated on the images and directed through the starting point into the pedicles and then vertebral bodies. Differences in the location of the entry point to the pedicle axis and distance from the screw edge to the inner pedicle cortices were measured to assess the safe angle and distance ranges within the pedicle.

Materials and methods

The lumbar spines of 40 adult, Chinese, volunteers were scanned on a GE Imatron CT scanner capable of providing three-dimensional reconstructions. The scanner used a slice thickness of 1.0 mm with an interval of 1.0 mm. Mimics 8.1 software was used to convert the acquired images to three-dimensional images of each lumbar segment from L1 through L5. There were 18 male and 22 female volunteers in this study; the age range was 17–71 years with an average of 47 years. The mean height was 168.6 cm with a range from 155 to 183 cm. The body weight was 43–93 kg with an average of 68.8 kg. Each patient had five discrete lumbar vertebrae which were reconstructed and analyzed separately.

Measuring the distance from the entrance point to the pedicle axis

Three different entry points were marked on the three-dimensional reconstructed image. Du described an entry point where the pars interarticularis converges at the accessory process, described as a “^”-shaped crest [5] (Fig. 1). Roy-Camille described a starting point 1 mm inferior to the inferior edge of the facet joint in line with the lateral margin of the facet joint [14] (Fig. 2). Magerl described a starting point at the lateral border of the superior facet where it intersects the mid-portion of the transverse process [11] (Fig. 2). The pedicle axis was drawn, connecting points through the central portion of the pedicle. The distances from each of the three different entrance points to this line as it exited the posterior elements were measured in millimeters (Fig. 3).

Measuring the safe range within the pedicle

A cylinder was made to simulate the outer diameter of varying size pedicle screws, using the Mimics 8.1 software (Fig. 4). Three different screw sizes were used: 6.0 mm circumference by 45 mm length for L1, 6.5 mm circumference by 45 mm length from L2 to L4, and 6.5 mm circumference by 40 mm length at L5. The simulated cylinder was placed in two different directions. Starting at the entry point, the simulated screw was directed tangential to the medial pedicle wall, and then separately from the same starting point tangential to the lateral pedicle wall at the pedicle isthmus (Figs. 5, 6). A separate line was then drawn through the mid-portion of the vertebral body, in an anterior–posterior direction on the CT cross section, at the area where the pedicle was also the narrowest. The angle that cylinder made, with the medial, and separately lateral, tangent and the line bisecting the mid-portion of the vertebral body was termed the transverse safe

Fig. 1 The morphology “^” shape crest of the lumbar spine

Fig. 2 The entrance points of three compared methods marked on the posterior vertebral cortex. *Red points* represent Roy-Camille's entrance point. *Yellow points* represent Du's entrance point. *Purple points* represent Magerl's entrance point

Fig. 3 Measure the distance between the entrance point and the pedicle axis

Fig. 4 Two cylinders simulate the pedicle screw

Fig. 5 The value of TSA when the cylinder is tangent with the medial wall

Fig. 6 The value of TSA when the cylinder is tangent with the lateral wall

angle (TSA; Figs. 5, 6). The data were then analyzed for each segment separately, comparing the three techniques at each vertebral segment L1 through L5. One-way analysis of variance and LSD/t were performed for statistical comparison. A P value of less than 0.05 was considered statistically significant.

Results

The distance from the entry point to pedicle axis was statistically significant between the methods from L1 to L5 ($P < 0.001$, F values were L1—10.77, L2—23.10, L3—52.32, L4—28.33, and L5—20.03). From L1 to L4 the entry point described by Du was closer to the pedicle axis than the other two techniques ($P < 0.05$). At L5 Magerl's entry point was closest to the pedicle axis ($P < 0.005$) (Table 1).

The safe range of TSA varied by level. There were no statistically significant differences between the three methods at L1 and L2 ($P > 0.05$, F values were L1—2.05 and L2—2.10). There were statistically significant differences from L3 to L5 (F values were L3—10.29, L4—9.52, and L5—30.62). At L3 and L4 the safe range of TSA measured by Du and Magerl's techniques were significantly larger than Roy-Camille's technique ($P < 0.05$). There were no significant differences between the Du and Magerl techniques at these levels. At L5 the safe range of TSA measured by Magerl's method were the largest among the three methods ($P < 0.05$; Table 2).

Discussion

A variety of conditions resulting from degenerative, traumatic, and other abnormalities of the lumbar spine are best managed by achieving spinal stability and attaining a solid fusion. To decrease failures in arthrodesis, a number of different devices have been developed to provide internal stability while the fusion is healing. Because the pedicle offers the strongest point of attachment to the spine, most spinal instrumentation systems use screws for fixation placed into the pedicle and then the vertebral body. However, a number of complications associated with pedicle screw fixation have been reported [1, 4]. One of the most serious complications related to pedicle screw usage is neurologic injury, secondary to misplaced pedicle screws abutting, or injuring, a nerve root or the cauda equina.

To minimize complications a number of techniques have been employed. These include varying points of insertion, pre-measuring and assessing the pedicle size and angle on the preoperative CT and/or MRI scan, use of intraoperative fluoroscopy or image guidance, use of electrophysiologic monitoring while entering and tapping the pedicle, probing the pedicle with small metal tools after entering the pedicle, etc. In developing countries, many of the above-listed techniques

Table 1 Comparison of the distance between the entrance point and the pedicle axis

	Du	Magerl	Roy-Camille
L1	1.22 ± 0.20*	2.83 ± 0.27*	2.04 ± 0.26*
L2	1.00 ± 0.22*	3.27 ± 0.22*	2.28 ± 0.27*
L3	0.74 ± 0.12*	2.78 ± 0.20*	3.52 ± 0.25*
L4	1.51 ± 0.21*	2.06 ± 0.27*	4.20 ± 0.31*
L5	2.85 ± 0.26*	1.61 ± 0.21*	5.38 ± 0.51*

Each parameter is mean ± SD; one-way analysis of variance is used

* $P \leq 0.001$

Table 2 Comparison of the safe range of transverse section angle

	Du	Magerl	Roy-Camille
L1	5.89 ± 0.67**	4.81 ± 0.57**	4.13 ± 0.61**
L2	6.11 ± 0.59**	5.10 ± 0.52**	4.59 ± 0.48**
L3	9.10 ± 0.66*	8.67 ± 0.69*	5.38 ± 0.54*
L4	12.82 ± 0.92*	12.49 ± 0.82*	7.86 ± 0.95*
L5	10.48 ± 0.76*	14.13 ± 1.11*	4.13 ± 0.84*

Each parameter is mean ± SD; one-way analysis of variance is used

* $P \leq 0.05$, ** $P \geq 0.05$

are not routinely available in the operating room. Because of this, we have chosen to study the potential anatomic relationships and therefore risks of using strict anatomic guidelines to choose the posterior pedicle screw entry point into the pedicle. There is a large a population of Chinese people throughout the world, but no data describing the pedicle morphology in that population. We have specifically targeted this group for assessment.

There are a number of techniques described to determine the location to enter the posterior aspect of the pedicle. The three we chose are often discussed and used (Roy-Camille, Magerl, and Du). Roy-Camille and Magerl suggest that the starting point for inserting a pedicle screw should be based on the anatomic relation of the facet joint and transverse process [11, 14]. Roy-Camille's entry point is the closest to the midline of the spine as the line through the plane of the facet joint is one of the crossing points. Magerl's entry point is further lateral, located at the nape of the neck of the superior articular process. Du's described entrance to the pedicle is located between Roy-Camille and Magerl's [5]. Though these different points are within millimeters of each other, the variations in pedicle angle and size can make the choice of the starting hole critically important in the ability to avoid violating a pedicle wall when screws are placed into and through the pedicle.

Pedicle violations by pedicle screws have been reported to occur more often through the medial and lateral walls than the superior and inferior walls [3]. One reason for this is that the pedicle heights are often greater than widths. Additionally, the cortical thickness of the superior and inferior walls is generally more than 2 mm, whereas the medial and lateral walls are less than 2 mm [10]. If different starting holes are chosen to enter the pedicle, the angle of insertion will differ and can lead to a relative diminution in the safe range for pedicle insertion through the isthmus of the pedicle. We have called this the safe range of the

transverse section angle (TSA). The larger the safe range of TSA, the greater the room available to contain the pedicle screw and, therefore, the less likely pedicle breakthrough will occur. The inserting safe range of TSA is an important parameter to use to compare the safety of different lumbar pedicle screw insertion techniques, which essentially measures the starting hole relative to the anatomic angle of the pedicle.

The key to a successful transpedicular screw insertion is that the small pedicle is correctly entered, and the walls not penetrated. Pedicle breakthrough occurs more easily in the medial and lateral walls if the entry point is far away from the axial line of the pedicle. Depending on the level in the lumbar spine, the pedicle morphology differs. At L1 and L2 the pedicle configuration is like an ellipse with small transverse diameters and TSA of the pedicle. There is no statistically significant difference by choosing any of the three entry points described in this study in terms of the safe range of TSA when the outer diameter of the pedicle screw is no larger than 6.0 mm at L1 or 6.5 mm at L2; though the entry point described by Du is closest to the pedicle access at L1 and L2. There were significant differences in the safe range of TSA between the three methods from L3 to L5, as the pedicle diameters and pedicle axis increase in obliquity, while the facet joints become more coronal. The latter is used as one point in the anatomic localization of the posterior pedicle. Both Du and Magerl's techniques can be applied at L3 and L4 because of their larger safe range of TSA. At L5, however, Magerl's method is a better choice because of the larger safe range of TSA. Roy-Camille's described technique gives the least amount of freedom in insertion angle of a pedicle screw as its safe range for TSA is the smallest, and the entry point furthest away, from the pedicle axis.

Mitra and Datir [13] and Hou et al. [8] observe that the entry point to the center of the lumbar pedicle migrates laterally from L1 to L5. At L5 it is lateral to the lateral border of the facet joint. Our findings agree with those observations. Therefore, one universal starting point is not appropriate for all levels. Earlier studies determined the center of the pedicle related to the region of the facet by visual examination in cadavers. The study reported here is more precise as we used the three-dimensional reconstructed CT scans to visualize the entire circumference and length of the pedicle. The safe range of TSA is an important parameter measured. It is difficult to measure in a cadaver. Measuring this parameter with Mimics 8.1 software and three-dimensional reconstructed images obviates measuring problems in cadavers.

Additionally, the position of the pedicle screw in the pedicle can be altered and measured accurately on the images using a simulated pedicle screw. The data, derived off CT images, are more reliable than manual techniques of measurement in a cadaver [10].

In summary, choosing the proper entry point to inserting pedicle screws is the first step to help avoid penetration of the pedicle wall. Understanding pedicle angles and morphometry also helps decrease the risk of pedicle violation during screw insertion.

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