The ipsilateral lamina–pedicle angle: can it be used to guide pedicle screw placement in the sub-axial cervical spine?

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Abstract Pedicle screws in the sub-axial spine are infrequently used because of concerns over their safety and difficulty in placement, despite their superior pullout strength. In the sub-axial cervical vertebrae, we have observed that the lamina appears to project at right angles to the ipsilateral pedicle axis. The aim of this investigation was to confirm the lamina orientation as a reliable landmark for pedicle screw placement. 80 digital cervical spine CT were analysed. The angle formed by the ipsilateral outer lamina cortex to the pedicle axis was recorded. A total of 398 vertebrae were analysed from patients with a mean age of 39.5 years (range 18–78). Average axial lamina–pedicle angle ranged from 96.6° at C3 to 87.2° at C7 in males, and from 95.6° to 87.5° in females. The angle formed by the posterior cortex of the lamina and the ipsilateral pedicle shows a high level of consistency for sub-axial cervical vertebrae ranging from 96° at C3 to 87° at C7. Although the angle is not exactly 90° at all levels as hypothesised, the orientation of the lamina, nevertheless, forms a useful reference plane for insertion of pedicle screws in the sub-axial cervical spine.

Keywords Cervical pedicle screw ·
Lamina–pedicle angle · Sub-axial cervical spine ·
Surgical technique

Introduction

Pedicle screws in the sub-axial cervical spine are infrequently used, with most surgeons preferring the lateral mass screw fixation technique. It is perceived that the benefits of their superior pullout strength over lateral mass screws [12, 18, 20] is not outweighed by the risks of spinal cord, nerve root or vertebral artery injury. Research has, therefore, been directed at gathering as much anatomical data as possible, to improve the safety of this operative technique.

Over the years, the focus has been on describing cervical pedicle morphology [6, 11, 14, 22, 24, 27, 30, 32, 35] to give the surgeon as much anatomical information as possible. In 1994, Abumi [1], one of the first surgeons to advocate cervical pedicle screw placement, stated that the angle of insertion should be between 25° and 45° to the sagittal plane, depending on the level at which the surgeon was operating. Since then, the ideal trajectory has been described as being between 35° and 55° [6, 11, 22, 32] from the sagittal plane.

More recently, there has been a trend towards studies assessing the use of fluoroscopic and computed tomography (CT) guidance, or computer-assisted surgical techniques to decrease perforation rates, with varying success. Kotil et al. [21] compared a freehand technique with that of using fluoroscopic guidance. They found that it did not improve success rates, and together with the increased surgical time, wound infection rate and radiation exposure, it was not necessarily beneficial to the patient. Ludwig et al. [23] also compared a freehand technique, this time with CT guidance, and again found that conventional surgery had the highest rate of safe pedicle screw placement.

Developments in computer-assisted surgery have subsequently been analysed and have shown a higher success

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rate than other image-guided techniques [19, 24]. However, as Kamimura et al. [13] quite rightly pointed out, the surgeon still needs to know the pedicle morphology to ensure that the computer guides the screws correctly. The overall consensus throughout these articles is that no matter what the technique, the surgeon needs to have a high level of three-dimensional anatomical knowledge, to ensure safe placement of cervical pedicle screws [15, 37].

We believe that any surgical technique, which involves estimating an angle from the sagittal plane, can be difficult to achieve accurately intra-operatively. We therefore looked at ways to try and improve the accuracy of pedicle screw placement in the cervical spine. If a reliable trajectory could be found that is easier to achieve than those previously suggested, then it would be beneficial to both the surgeon and patient. Estimating a 90° angle from a consistent anatomical landmark should, in theory, be easier to perform when compared with other techniques.

A recent study [10] has shown that the contralateral lamina can be used as a guide for the trajectory of pedicle screw placement. However, this trajectory can still be difficult to perform accurately, even with extensive dissection. In the sub-axial cervical vertebrae, we observed that the lamina appeared to project at right angles to the ipsilateral pedicle axis. If this was shown, then it could provide a more reliable surgical reference than those previously described.

The aim of this study was to test a specific hypothesis in the axial plane, and we therefore did not analyse the angle of insertion in all three dimensions. Ludwig et al. [22] described the angulation of the trajectory of the pedicle screw in the sagittal plane as ranging from 8.63° cephalad at C3 to 1.62° caudal at C7.

Our hypothesis is that in the sub-axial spine, the angle measured between the lamina and its ipsilateral pedicle is 90°. The aim of this study was to confirm this angle as a reliable landmark for pedicle screw placement. We performed a CT-based study to analyse this.

Materials and methods

The CT scans of 40 males and 40 females were analysed, all of which had previously been performed for clinical reasons unrelated to this study. The age range included was from 18 to 80 years. CT scans were excluded if the report suggested the presence of tumour, malformations, burst or sagittal split fractures of the vertebral bodies, or severe degeneration. Individual levels were also excluded if the visualisation of the lamina on the CT did not allow accurate placement of a tangential line (this is likely to be because of the angle of the gantry).

Fig. 1 Angle between the posterior cortex of the lamina and the pedicle axis

Axial CT views were analysed on the Impax PACS system (Agfa) allowing exact measurements to be taken. The slice width was 1.25 mm, and angles could be measured to an accuracy of 0.1°.

Simple patient demographics were recorded, along with the indication for the scan. The average age was 36 years in the male group and 43 in the female group (range 18–78 years). The CT scans were almost exclusively performed as part of a trauma screen following road traffic collisions or falls from height.

A line was drawn parallel to the posterior cortex of the lamina, and then the angle measured by drawing a line along the axis of the ipsilateral pedicle (Fig. 1). Both right and left lamina–pedicle angles were recorded.

The measurements were carried out by two observers, one with an orthopaedic background and the other from radiology. Data were collated within a Microsoft Excel spreadsheet.

Simple statistics, such as mean and standard deviation, were performed using the Excel spreadsheet, whilst the concordance correlation coefficient (intra- and inter-observer error), Bland–Altman plot and student's paired *t* test were calculated via the MedCalc statistical software package (www.medcalc.be).

Results

A total of 80 CT scans of patients were analysed, which allowed 398 levels to be evaluated. The C7 vertebrae of two patients had to be excluded because the axial images

did not allow visualisation of the ipsilateral lamina and pedicle together.

The mean ipsilateral lamina–pedicle angle ranged from 96.6° at C3 to 87.2° at C7 in males, and from 95.6° at C3 to 87.5° at C7 in females. The results are summarised in Table 1.

There was a significant difference between the male and female averages, and also between the mean values for the right and left sides in males ($P < 0.05$, student's paired t test). However, on comparing the right and left sides in women, although a difference was observed, it did not reach statistical significance ($P > 0.05$).

Table 1 Average ipsilateral lamina–pedicle angle at each vertebral level

	Angle	
	Right	Left
Males		
C3		
Mean	95.7	96.6
SD	3.2	3.5
C4		
Mean	96.1	96.6
SD	2.9	3.3
C5		
Mean	93.8	94.4
SD	3.7	3.8
C6		
Mean	90.8	91.0
SD	3.1	3.0
C7		
Mean	87.2	88.0
SD	3.5	3.4
Females		
C3		
Mean	94.8	95.6
SD	2.5	2.7
C4		
Mean	94.5	95.4
SD	2.6	3.3
C5		
Mean	93.0	92.8
SD	3.1	3.3
C6		
Mean	90.3	90.3
SD	2.4	2.3
C7		
Mean	87.5	87.9
SD	2.1	2.1

SD standard deviation

Measurements were performed twice in 11 patients (55 vertebrae, 110 angles) to calculate intra-observer error. The concordance correlation coefficient was 0.9 (95% CI 0.86–0.93), showing that this is a reproducible measurement.

The inter-observer error was also calculated by both observers measuring the angles on 11 patients concurrently (55 vertebrae, 110 angles). The concordance correlation coefficient was 0.76 (95% CI 0.63–0.84) and a Bland–Altman plot showed a mean difference of 0.6° between our measurements. The main variable in our technique was in the individual observer's interpretation of the position of the axis of the pedicle. However, these results are satisfactory and showed that we could perform the measurements independently.

Discussion

Abumi [1] is accredited with the first description of the cervical pedicle screw insertion technique, with all subsequent methods being compared with his approach. Despite the biomechanical studies showing that pedicle screws have a superior pullout strength when compared with lateral mass fixation techniques [12, 18, 20], there is still a reluctance in the spinal community to use them. A predominantly lumbar spine-focussed study has suggested that pedicle screws are the 'gold-standard' and 'can be placed safely wherever a pedicle screw can be accommodated' [9]. However, the general consensus throughout the cervical spine literature is that they 'should not be used routinely' due to the high risk of malplacement and pedicle perforation [26, 36].

The main concerns with pedicle screw placement are that of pedicle perforation leading to spinal cord, vertebral artery or nerve root injury. However, lateral mass screws are not without their risks [25], and pedicle screw placement in the lumbar spine has a documented perforation rate of over 5% [8] despite the larger diameter of the pedicles. Documented cervical pedicle perforation rates vary from 4 to 87.5% [2, 4, 5, 11, 16, 17, 24, 29], with cadaveric studies reporting a higher incidence than comparable clinical experiments. However, throughout the literature there is a distinction between 'minor' and 'critical' perforation rates, with the former unlikely to be of clinical significance.

Morphological studies have been performed regularly, since the publication of Abumi's [1] technique in 1994, to increase our knowledge and understanding of the anatomical variance of individuals undergoing this procedure. All of them agree that the pedicle morphology varies among cervical levels, individuals and gender [7, 10, 30]. One study has also shown that an individual pedicle is unlikely to be uniform in shape along its axis [33], which also impacts on the safety of pedicle screw placement. Cervical

pedicles are generally oval in shape, with the height being larger than the width [6, 14, 27, 35]. The lateral cortex is also thinner than the other cortices [14, 28, 33], making it the most likely to be perforated [11].

The vertebral artery is more likely to be injured than the nerve root [22], with the spinal cord being the structure least likely to get injured [24] because it is adjacent to the relatively thicker medial cortex. However, the vertebral artery is not directly adjacent to the lateral cortex and so minor perforations laterally do not always cause a vascular injury. Kast et al. [17] found that if the foramen transversarium was compromised by less than 25% of its diameter, then the artery was not damaged. Abumi et al. [1] found no neurovascular complications in their series, despite known lateral cortex perforations. On the other hand, studies have shown that if they do occur; superior, medial and inferior perforations will almost always damage the nerve root or spinal cord, given that these structures are adjacent to the pedicle in these planes [35, 36].

Pedicle screw insertion techniques described in the literature are based on cadaveric and CT studies. Insertion angles of between 25° and 55° to the sagittal plane have been described [1, 6, 11, 12, 22, 24, 27, 32, 35], with the ideal trajectory varying between levels. Hacker et al. [10] have recently performed a CT-based study, assessing whether the contralateral lamina could be used as a landmark. They concluded that if the screw trajectory was placed parallel to the contralateral lamina, then the screw could be positioned safely within the pedicle. They measured the angle the lamina made with the sagittal plane, finding it to be 50°, consistent at each vertebral level. Their findings, therefore, supported the work of Sakamoto et al. [32], who also describe this angle of insertion.

Any surgical technique is easier to perform if the operator has a constant landmark to reference from. It is easier to measure an angle of 90° freehand, than to estimate the angles previously described. A surgeon is more likely to over-compensate laterally, where the cortex is thinner, than medially when estimating these angles because of the fear of spinal cord injury. We had observed that the ipsilateral lamina–pedicle angle was approximately 90° and therefore felt that this could be used as described. However, our hypothesis was not fully substantiated by this study, because the ipsilateral lamina–pedicle angle was not exactly 90°. Despite this, we do feel that the results of our work form useful anatomical information for the spinal community. The results show that the angle is consistent, with a low standard deviation at each individual level. We have also shown that the relationship of the pedicle to its ipsilateral lamina changes with each vertebral level, the angle decreasing as the levels progress caudally. With the need for three-dimensional anatomical knowledge, it is beneficial to know this when inserting cervical pedicle screws.

Recently, the various image-guidance modalities were analysed to try and decrease perforation rates intra-operatively. Kotil and Bilge [21] compared a freehand technique with fluoroscopic guidance, concluding that the use of anatomical landmarks was as effective as intra-operative imaging. (However, their evaluation of the cervical spine was limited, with only ten screws placed.) Ludwig et al. [23] examined the use of CT guidance and found that it did not decrease pedicle perforation rates compared to Abumi's technique (18 vs. 12%). A further study [24] compared a computer-assisted technique with that of freehand surgery. A decrease in perforation rates from 66.5 to 10.6% was shown. Three other studies have also found a benefit in using computer guidance during such surgery [13, 19, 31]; however, no matter which technique is employed, there is still a need for the surgeon to understand the anatomical landmarks.

We, along with the paper by Hacker et al. [10], advocate the use of the posterior elements as a reference for the trajectory of pedicle screw insertion. However, there is a significant limitation to both our techniques, which they also mentioned. Our measurements are only taken from CT scans with normal appearances of the posterior elements, and so if the anatomy of the lamina has been changed in any way, in particular by previous surgery, tumour destruction, rheumatoid arthritis or cervical spondylosis, then the lamina cannot be used as a reference tool. Knowledge of other surgical techniques will be needed in these situations.

Whatever the image-guidance technique used, the general consensus throughout the literature is the need for pre-operative CT assessment of the width of the pedicles [3, 10, 15, 29, 34]. Pedicle widths of less than 4 mm have been reported [14], with one paper suggesting that as many as 83% of pedicles may be smaller than the screw diameter [29]. Most papers agree that the fourth and fifth vertebrae have the smallest pedicle width; with others suggesting vertebral levels three and six [3, 17, 23, 27, 29]. Pre-operative assessment ensures that the surgeon does not place a screw in a pedicle whose diameter cannot realistically accommodate one. Ludwig et al. [23] have suggested that pedicles should not be instrumented if they have a width of less than 4.5 mm.

Along with other authors [2, 9], we believe that pedicle screws are safe to insert by surgeons with the appropriate experience. As long as appropriate pre-operative imaging protocols are adhered to, then perforation rates can be kept to a minimum. Even with the increasing technology available to help with surgical techniques, there is still a need for every surgeon involved to have sound anatomical knowledge [13, 31, 37]. This study aids anatomical understanding in those surgeons who advocate pedicle screw usage in the cervical spine.

Limitations

The CT gantry was not set parallel to the lamina because the imaging was not performed specifically for research purposes. This could have a bearing on the measurements taken, although we did exclude any levels where the morphology of the lamina was unclear.

This study has only analysed the pedicle screw trajectory in relation to the ipsilateral lamina, and not the optimal insertion point.

Conclusion

The advantage over previously described techniques of using the lamina as a reference in the placement of cervical pedicle screws is that the anatomical plane used is independent of the position of the patient. The angle formed by the lamina and ipsilateral pedicle shows a high level of consistency for sub-axial cervical vertebrae, ranging from 96° at C3 to 87° at C7. Although the angle is not exactly 90° at all levels as hypothesised, the lamina nevertheless forms a useful reference plane for insertion of pedicle screws in the sub-axial cervical spine. We should, however, emphasise that cervical pedicle screws should only be placed by surgeons with sufficient surgical experience.

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