Preoperative imaging of cervical pedicles: comparison of accuracy of oblique radiographs versus axial CT scans

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Abstract In spite of concerns about safety during their insertion, cervical spine pedicle screws have demonstrated biomechanical superiority over lateral mass screws in several biomechanical studies. One of the concerns for placement of cervical pedicle screws is their small size. Preoperative planning with computed tomography to assess pedicle width has been shown to be extremely accurate and is recommended by several authors. To date there has been no study assessing the accuracy of oblique radiographs for pedicle measurement. We sought to compare accuracy of the oblique radiographic measurements of cervical pedicle width with axial CT scan measurements. Five fresh-frozen human cadaveric cervical spines C3–C7 were studied. Thin cut 1.25 mm computed tomography axial cuts were made through the pedicle isthmus. Oblique radiographs at 35°, 45°, and 55° angles were taken of the right and left pedicles of each specimen using a standardized technique. Each radiograph contained a pin of known length to correct for magnification. All pedicles were again measured and corrected for magnification using the standard pin. Corrected

oblique radiograph measurements were compared to CT for each specimen. The outer pedicle width was measured and agreed upon by consensus. The radiograph measurements were on average significantly larger than CT measurements for the pedicles indicating that the pin standard did not completely correct magnification. Plain radiographic data failed to reveal that one oblique angle was favorable to another in terms of magnification or precision. Plain radiographs at oblique angles do not provide accurate measurements of subaxial cervical pedicles at 35°, 45°, or 55° angles. We recommend that thin cut axial CT scans be obtained on all patients prior to transpedicular fixation in the cervical spine.

Keywords Cervical pedicles · Pedicle measurements · Pedicle screws · Oblique radiographs · CT scans

Introduction

There is significant debate among cervical spine surgeons on the merits of lateral mass and pedicle screws, the two most commonly used posterior fixation methods for the subaxial cervical spine. Lateral mass fixation is technically reliable but has demonstrated inferior biomechanical characteristics when compared to pedicle screws [9, 11–13]. This is particularly evident when there is destruction of bone stock by fracture, tumor, or revision surgery. Cadaveric studies have shown subaxial pedicle screws to be biomechanically superior to lateral mass fixation [15, 16, 23, 25, 30]. Superior strength of pedicle fixation allows correction of posttraumatic kyphosis from a posterior approach alone even when neural compression is present [3, 5]. This fixation has been adopted by many despite significant risks to neurovascular structures during pedicle screw

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placement. It seems these risks are manageable as experts have reported large series of cervical pedicle screw placements (over 800 combined) with only one vertebral artery injury and two cases of screw induced radiculopathy [4, 40]. None of these complications had long term sequelae.

Despite clinical success there is still considerable concern with pedicle screw fixation as anatomic studies have demonstrated critical perforation rates of 7–15% with subsequent injuries to the vertebral artery or neural elements [18, 21]. Concern is greatest for a surgeon who is new to the technique or performs the procedure infrequently. Abumi et al. [1] first described the most commonly used insertion technique which relies on direct exposure. Newer techniques have been described that rely on anatomic landmarks [7, 14, 19, 20, 24, 27], direct exposure [1, 2, 20, 22, 29, 31] and most recently by computerized image-guided navigation system [6, 17, 31, 34–36]. These techniques evolved to reduce the rate of pedicle perforations. However, even with some of the computerized insertion techniques unacceptable rates of pedicle perforation have been realized in cadaveric studies [26, 28, 32, 35].

Most cervical spine surgeons agree that a detailed understanding of cervical spine anatomy is necessary to avoid injury to the vertebral artery, spinal cord, or nerve roots during cervical pedicle screw placement. Cervical pedicle morphometry has been studied in detail toward this goal [10, 30, 33, 38, 39]. However, individual variations exist and some ethnic populations may differ from each other [42]. With this in mind it is critical to obtain a preoperative thin sliced CT scan on every patient where cervical pedicle screw fixation is considered. It has been shown that CT measurements of pedicles are extremely accurate and are consistent with measurements directly obtained with a micrometer [18]. It is clear that some pedicles in the subaxial cervical spine are too small for the most frequently used 3.5 mm screws and preoperative knowledge of this is critical. CT images allow for appropriate preoperative planning and when combined with expert knowledge of the anatomy safe cervical pedicle screw placement can be achieved.

Preoperative measurement of pedicles using thin sliced CT images is the gold standard. Some believe that CT technology should be supplanted or even replaced by oblique radiographs of the cervical spine. A recent report evaluated placement of cervical pedicle screws using intraoperative oblique fluoroscopy. Postoperative CT images revealed a 4.0% perforation and 10% screw exposure rates. They also noted a low incidence of radiculopathy and vertebral artery injury [41]. Oblique radiographs are more readily available and it has been determined that they are adequate for templating pedicle screw placement in lumbar spine procedures as the outer diameters are up to two times larger than the cervical spine [42]. It is logical to consider

them for templating pedicle screw placement in cervical spine procedures although the margin for error is much narrower in the cervical spine as outer pedicle width can be equal or less than 4 mm in many instances, most commonly at C3 [18].

A comparison of the accuracy of oblique plain X-rays compared to CT scans has not been previously reported. In this study, the authors sought to evaluate the accuracy of plain radiographs taken at various oblique angles and compare these measurements with CT scan measurements of the same specimens in order to determine whether oblique radiographs should supplant or replace CT images.

Materials and methods

Five fresh-frozen human cadaveric cervical spines (3 male, 2 female) were harvested from C3 to C7. The average age of donors was 71.2 years (Range 65–79 years). Specimens had no evidence of developmental, congenital, traumatic, infectious, or neoplastic processes. Specimens were stored at (–20) degrees Celsius.

Specimens were statically fixed to a board with twine to facilitate standard oblique radiographs of each specimen. Initial scout views were obtained in the AP and lateral planes to determine that the vertebral bodies were in proper alignment on the board. Lateral radiographs were scrutinized and specimens repositioned until the anterior aspect of the C5 vertebra was parallel to the board below. Once ideal position was obtained the specimens were statically fixed to the board. A standard pin of known length was then affixed to the board as close to the specimens as possible on the right side of each cadaveric spine (Fig. 1).

Fig. 1 Experimental setup for oblique radiographs with saw bones cervical model in place, *black arrow* points to position of standard pin. Height of the board was altered using standard pegs in order to create 35°, 45°, and 55° angle from the table below

Oblique radiographs at 35°, 45°, and 55° were obtained of each cervical spine to focus on both the left and right pedicles with the beam centered on C5. The source beam positioned a standard 101.6 cm above the X-ray plate. All specimens were positioned by the same researcher and all X-rays were taken by the same technologist. A total of 30 radiographs were obtained, 6 for each specimen. Thin 1.25 mm axial CT scans were obtained of each specimen (Lightspeed, General Electric, Milwaukee, WI).

Pedicle measurements were obtained by three readers simultaneously: a fellowship trained spine surgeon, a musculoskeletal radiologist, and a senior orthopaedic resident. The measurements were obtained by consensus between the three readers. On the oblique radiographs only the outer pedicle diameter was measured. Morphometric studies have confirmed that pedicle width is the critical measurement as only 2.4% of pedicles have a height measurement larger than width; and the outer pedicle diameter is more important than the inner diameter in regards to pedicle perforations with screw insertion [18]. Additionally the standardized pin was measured on each digital radiograph (Fig. 2). All measurements were obtained on PACS workstation (General Electric Medical Systems, Milwaukee, WI) both for the plain radiographs and CT scans. The axial cut with the widest outer pedicle width was used for the measurement, again only the outer pedicle diameters were measured by CT (Fig. 3). Fifty

Fig. 2 45° oblique radiograph demonstrating the pedicle measurements C3–C7 obtained with the PACS workstation, arrows point to digital measurements of each pedicle. Measurement of standard pin is evident as well

Fig. 3 Axial cut of the CT scan where the widest portion of the pedicle isthmus was measured. The outer diameter of the pedicle was measured as shown. The vertebral artery (A), spinal canal (S), vertebral body (VB) and pedicle (P) are labeled

axial cuts were reviewed in order to accurately measure the pedicles for all specimens. Pedicle widths were not measured directly with a micrometer as the CT measurements can be accepted as a true representation of pedicle width [18].

To confirm the accuracy of measurement correction in vitro using the pin as described above an additional basic science study was performed. A standardized radiolucent board was constructed with several radiopaque pre-cut rods of known width affixed to it. All of the rods were measured with a micrometer to the tenth of a millimeter prior to fixation. The board was constructed to have a similar width and length of a human cervical spine. Several X-rays were obtained of the standard at varying heights 0, 5.1, 10.2, 15.2, 30.5 cm above the X-ray plate. These heights were chosen to yield a variety of data points and to mimic the height of the specimens on the board during the oblique radiograph protocol. The bar lengths were measured on each plain radiograph with a micrometer to determine the relationship between height of an object from the X-ray plate and magnification.

Statistical methods

A correction factor was calculated for each oblique radiograph obtained (actual pin length/radiographic measurement of pin). Magnification error was corrected for each pedicle consensus measurement with this correction factor. Correlations for corrected plain radiographic and CT pedicle

measurements were calculated using the Spearman rank correlation coefficients.

Results

For the 50 pedicles in this study a total of 150 radiographic and 50 CT measurements were obtained. There was no correlation between the CT measurements of the pedicle widths and the values of the corrected pedicle widths as measured on the oblique radiographs at any angle (Fig. 4). The radiograph measurements were on average significantly larger than CT measurements for the pedicles indicating that the pin standard did not completely correct magnification. Plain radiographic data failed to reveal that one oblique angle was favorable to another in terms of magnification or precision. Given the setup for oblique radiographs it was clear that the magnification on the plain radiographs would increase as the angle increased from 35° to 55°. Our data demonstrates the increasing power of the correction factor at the higher oblique angles. Additionally it was noted that the right pedicles consistently had a more powerful correction factor and smaller corrected measurements than the left pedicles (Fig. 5). However, neither the right or left pedicle plain radiographic measurements correlated with corresponding CT data. Additional studies with standard bars indicated that magnification increases linearly with height from the radiographic plate (Fig. 6) and that objects separated by a horizontal distance, similar to the right and left pedicles, are not magnified differently.

Discussion

In our study we evaluated the accuracy of 35°, 45°, and 55° oblique radiographs for cervical pedicle width measurement. A pin of known size was placed alongside the

Fig. 4 CT and 55° oblique radiograph measurement plot demonstrating lack of correlation with $R^2 = 0.59$. Oblique measurements for each cervical level C3–C7 were plotted against CT values with similar results not shown here. None of the obliques at any cervical level correlated with CT measurements

Fig. 5 Correction factors plotted against radiographic angle. Correction increases as radiographic angle according to experimental setup. Additionally the correction factors for the right pedicles were consistently greater consistent with pin placement

Fig. 6 Percent magnification plotted against height of pin from radiographic plate demonstrating linear increase in magnification

cadaveric specimens to help control for magnification. Our data demonstrates that oblique digital radiographs do not replicate the measurements obtained by axial CT scans at any angle. Additionally our study demonstrated that placing a pin of known size next to the specimen is insufficient for magnification correction with digital radiographs.

Notably the right pedicle measurements in our study were consistently smaller than the left pedicle measurements after correction although still significantly larger than the CT measurements. This finding is easily explained by our protocol where the pin was consistently placed on the right side of the specimen. In this position the standard pin was uniformly located closer to the radiographic source when oblique radiographs were taken of the right pedicles compared to the left pedicles. Consequently the right pedicles were corrected by a larger factor.

Basic radiographic analysis with radiographic bars confirmed that magnification increased linearly as an object's height is increased from the radiographic plate.

This relationship explains why inclusion of a standard radiographic bar next to the specimen was ineffective. To accurately correct for magnification with plain radiograph a standard must be placed directly next to or within the pedicle to be measured. In our study the pin was placed within the radiograph but was several centimeters away from the pedicles measured. Unfortunately, in a human being it would be impossible to get a standard pin close enough to the pedicle given the intervening soft tissue. Our method allowed for some correction of magnification but not enough to recreate the accuracy of CT scans.

CT scans are becoming the gold standard for evaluation of the cervical spine and plain radiographic magnification errors are well described. A recent review highlighted the necessity of CT scans when measuring radiographic findings associated with occipitocervical dissociation or Jefferson fractures because of magnification with plain radiographs [8]. In cervical spine surgery CT information is invaluable for preoperative planning and for technique adjustments. A CT study of cervical pedicles looked at insertion angles and found that a 50° insertion angle in the transverse plane allowed for increased space available for a transpedicular screw as compared with a 20° insertion angle [37]. Anatomic studies confirm that up to 4% of cervical pedicles lack an intramedullary canal and many pedicles will have an outer diameter less than 4 mm particularly at C3–C4 [18]. These studies highlight the necessity of extremely accurate preoperative templating to ensure safe and efficacious transpedicular fixation with currently available screw sizes. At this time the only way to accomplish this is with thin cut axial CT scans.

Recently the interest in cervical pedicle screws is growing exponentially in the spine community world wide. Positive experience with the technique in the thoracic and lumbar spine attracts many surgeons to entertain pedicle screw fixation in the cervical spine. Although our work and that of others demonstrates biomechanical superiority of cervical pedicle screws when compared with other posterior fixation techniques there are significant risks to consider. Our goal is to inform the spine community that placement of cervical pedicle screws requires adequate technical support in the form of preoperative CT imaging in addition to detailed knowledge of cervical pedicle anatomy and superb manual skills. CT imaging is required to determine if a patient is an appropriate candidate for this complex and delicate procedure and we do not recommend attempting cervical pedicle screw placement in communities where such technical support or expertise are not available.

Limitations of this study relate to the placement of the radiographic standard and plain radiography protocols as described above. Ideally two identical standard pins should be placed on either side of the specimen eliminating the

difference between right and left pedicles. Although this would have improved our data it would not have changed the final conclusion. Our analysis with standard bars and plain radiographs concluded that magnification increases with distance from the plate and would also change if the source distance from the plate was altered. With these tests we determined that a radiographic standard would have to be placed within a few millimeters of or within the pedicle to be measured in order to control for magnification and yield the accuracy of CT scans. This could be performed in a follow up cadaveric study but would be irrelevant in clinical practice. Additionally the use of a board to create the standard oblique angles resulted in rather large differences in height of the pedicles from the horizontally placed radiographic plate between the 35°, 45°, and 55° obliques.

There are several anatomic constraints that limit the ability to accurately measure pedicle diameters with plain radiography. Due to the natural curvature of the cervical spines in the sagittal plane the heights of individual pedicles varied from C2–C7 which could have altered accuracy even between spinal levels. Many of the specimens were of advanced age and had evidence of degenerative changes including sagittal plane deformity, anterior osteophytes, and facet arthropathy. It is likely that the presence of degenerative changes increases the difficulty of pedicle measurement on plain radiographs significantly. On the other hand operating on an elderly population is the norm for a contemporary spine surgeon so our cadaveric model is not far from the reality of everyday practice. The pedicles also vary in axial angulations between spinal levels which could make a 24° most accurate for one spinal level and a 60° oblique for another on identical specimens [18]. Lastly, our radiographic beam was centered on C5 which could have introduced error when measuring pedicles at other levels. Many of these errors could be corrected by placement of a standardized pin at the level of the pedicle, however this is not clinically useful and it is clear that many errors related to pedicle anatomy would not be correctable.

Conclusion

Plain radiographs at oblique angles did not provide accurate measurements of subaxial cervical pedicles at 35°, 45°, or 55° angles. Inclusion of a radiographic standard pin does not correct for the magnification error associated with this technique. We recommend that thin cut axial CT scans be obtained on all patients prior to transpedicular fixation in the cervical spine. Accurate preoperative templating can help minimize this technique's rare but devastating complications.

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