

Pedicle Screw Fixation in the Cervical Spine

Rongming Xu, MD, Nabil A. Ebraheim, MD, and Martin Skie, MD

Abstract

Pedicle screw fixation of the lower cervical spine is a new technique that provides an alternative to posterior lateral mass plating. Although biomechanical studies support the use of pedicle screws to reconstruct the cervical spine, placing screws into the small cervical pedicle poses a technical challenge. Penetration of the pedicle is the primary complication associated with screw insertion in the lower cervical spine. Pedicle screw fixation at the C2 and C7 pedicles in conjunction with use of plates for occipitocervical or cervicothoracic plating is becoming an accepted technique; however, pedicle screw fixation should not be routinely used at the C3–C6 levels. It may be indicated in patients who have osteoporotic bone or when rigid internal fixation cannot be achieved by conventional techniques.

Pedicle screw fixation of the cervical spine was pioneered in 1964 by Leconte,¹ who inserted screws into the C2 pedicles for treatment of traumatic spondylolisthesis of the axis. Leconte's work was followed by that of Saillant and Bleyntia² in 1979.

In 1984, Borne and colleagues³ described using pedicle screw fixation for the treatment of pedicular fractures of C2. Recently, this technique has been used for caudal fixation for occipitocervical plate fixation.⁴ Pedicle screw fixation was not used in the lower cervical spine until 1995.

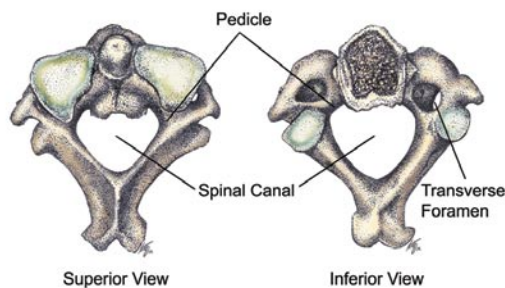
Abumi and colleagues,⁵ followed by Jeanneret and colleagues,⁶ were the first to introduce screws into the pedicles in the lower cervical spine to treat fractures and dislocations. As a result of successful outcomes in the treatment of various unstable cervical spine disorders, pedicle screw fixation in the cervical spine has been the subject of several studies involving anatomy, biomechanics, and clinical application. In this article, we review the current state of pedicle screw fixation in the cervical spine.

SURGICAL ANATOMY

Pedicles

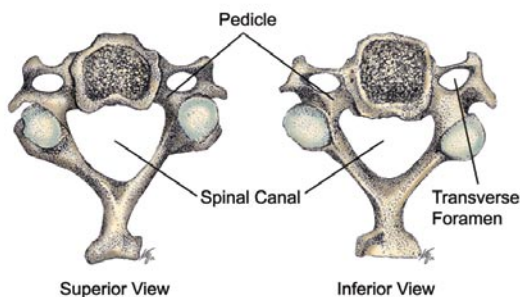
The C2 pedicle is unique in the cervical spine and has an oblique orientation from the lateroinferior to the mediosuperior. It is situated directly posteromedial to the transverse foramen and covered medially by the superior articular facet (Figure 1). The superior pedicle is wider than the inferior pedicle. The narrowest portion of the pedicle is the area adjacent to the transverse foramen.⁷ The lateral wall of the pedicle in this area is thin compared with the medial and superior walls and is more vulnerable to penetration by a pedicle screw.

The pedicles of the C3 through C6 vertebrae are more uniform. They are short, tubular structures originating from the posterolateral corner of the vertebral body and attaching to the anteromedial aspect of the lateral mass between the superior and inferior articular processes. In the transverse plane, the pedicle is between the spinal canal and transverse foramen of the



Second Cervical Vertebra (Axis)

Figure 1. Axis from superior and inferior views.



Fifth Cervical Vertebra

Figure 2. C5 vertebra from superior and inferior views.

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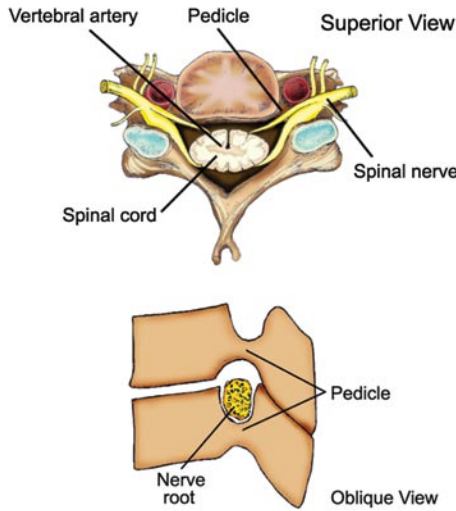


Figure 3. Anatomical relationships of pedicle to adjacent neurovascular structures.

transverse process oriented posterolateral to anteromedial (Figure 2). In the sagittal plane, the C3–C4 pedicle is slightly cephalad, the C5 horizontal, and the C6–C7 slightly caudal.⁸ Pedicle dimensions are smaller in the lower cervical spine than in the thoracic or lumbar region. For C3–C7, pedicle widths average 5 to 6 mm, and pedicle heights average 7 to 8 mm (Table).^{9–11} In general, pedicle width is smaller than pedicle height, and the lateral cortex of the pedicle is thinnest. The C7 pedicle is slightly larger than the C3–C6 pedicle. In most cases, the C7 vertebra has no transverse foramen, as it is a transitional vertebra.

Vertebral Artery

The vertebral artery is the main tributary of the cervical spine. It originates from the subclavian artery on the right side and from the brachiocephalic artery on the left side at the T1–T2 level or the lower portion of the T1. At the C7 level, the vertebral artery is situated lateral to the vertebral body, anterior to the spinal nerve and in the front of the midportion of the lateral mass. It enters the transverse foramen at C6 and courses cephalad through all the foramina above. In the transverse plane, the vertebral artery lies lateral to the pedicle and in front of the lateral mass (Figure 3). As it courses cephalad

from C6 to C2, it becomes gradually more anterior and medial. Within the transverse foramen of C2, the course of the vertebral artery is inferomedial to superolateral. However, it should be noted that the course of the vertebral artery within the C2 transverse foramen may vary. The C2 pedicle may be significantly smaller if the vertebral artery courses more medial within the transverse foramen. As the vertebral artery emerges from the transverse foramen of the atlas, it courses medially, rests on the anterior portion of the superior surface of the curved posterior ring, and enters the dura at the lateral aspect of the foramen magnum, becoming the basilar artery.

Spinal Nerve

The spinal nerve exiting from the spinal canal passes through the interpedicular foramen, which is bounded by the adjacent pedicles superiorly and inferiorly, the posterolateral wall of the vertebral body anteriorly, and the anteromedial aspect of the superior articular process posteriorly. Laterally, in the intertransverse foramen, it divides into a larger ventral ramus and a smaller dorsal ramus. The ventral ramus of the cervical spinal nerve courses on the transverse process anterolaterally to form the cervical plexus and the brachial plexus. The dorsal ramus branching off the spinal nerve in the intertransverse foramen runs posteriorly against the anterolateral corner of the base of the superior articular process just above the origin of the posterior ridge of the transverse process and supplies the facet joint, ligaments, deep muscles, and skin of the posterior neck. On oblique sagittal images of the cervical spine, the cervical nerve is located in the lower portion of the interpedicular foramen and occupies the majority of the inferior part of the intertransverse foramen (Figure 3).^{12,13} Xu and colleagues¹⁴ found that there is no space between the pedicle and the superior nerve root in the lower cervical region; however, there is a little space (~1.5 mm) between the pedicle and the inferior nerve root. The C7 spinal nerve is relatively larger and closer to the anterior aspect of the lateral mass because its course is more posterior in the transverse plane.

BIOMECHANICS

The biomechanical advantages of pedicle screw fixation in the thoracolumbar spine have been extensively documented and widely accepted. In contrast, biomechanical studies evaluating the pedicle screw construct

Table. Anatomical Parameters of the Cervical Pedicle

| Level | Mean (SD) Pedicle Widths and Heights (in mm) | | | |
|-------|--|------------|---|-----------|
| | Panjabi et al (1991) ⁹ | | Xu et al (1995) ¹⁸ & Ebraheim et al (1996) ¹⁹ | |
| | Width | Height | Width | Height |
| C2 | 8.0 (0.2) | 10.5 (0.3) | 8.3 (1.3) | 7.3 (1.3) |
| C3 | 5.6 (0.5) | 7.4 (0.4) | 4.7 (0.9) | 5.8 (0.7) |
| C4 | 5.4 (0.5) | 7.4 (0.5) | 4.7 (0.7) | 6.6 (0.6) |
| C5 | 5.6 (0.4) | 7.0 (0.4) | 4.9 (0.8) | 6.2 (0.8) |
| C6 | 6.0 (0.4) | 7.3 (0.4) | 5.1 (0.7) | 6.1 (0.8) |
| C7 | 6.6 (0.4) | 7.5 (0.3) | 6.2 (0.7) | 7.0 (0.7) |

in the cervical spine are few in number, as application of the technique in the cervical spine is new.

Using a bovine cervical spine model, Kotani and colleagues¹⁵ tested 7 stabilization constructs— anterior iliac bone graft, anterior locking plates (Acromed, Cleveland, Ohio; and AO [Arbeitsgemeinschaft für Osteosynthesefragen]), posterior triple-wiring, posterior or lateral mass plating, combined anterior and posterior constructs, and pedicle screw fixation—under 4 loading models in 1- and 2-level instability patterns. In 1-level constructs, pedicle screw fixation and combined anterior plating and posterior wiring provided stability equal or superior to that of anterior or posterior plating or posterior wiring alone. However, the pedicle screw construct offered increased stability over that of conventional anterior or posterior techniques for 3-column instability and 2-level reconstruction.

Using a human cervical spine model, Jones and colleagues¹⁶ compared the pullout strengths of pedicle and lateral mass screws. Mean load to failure was significantly higher in pedicle screws (677 N) than in lateral mass screws (355 N). Of note is that no significant difference in pullout strengths was found between 2.7- and 3.5-mm pedicle screws. It has been suggested that the same amount of cortical purchase is achieved with screws of different sizes in the pedicle. The biomechanical advantages of pedicle screw fixation in

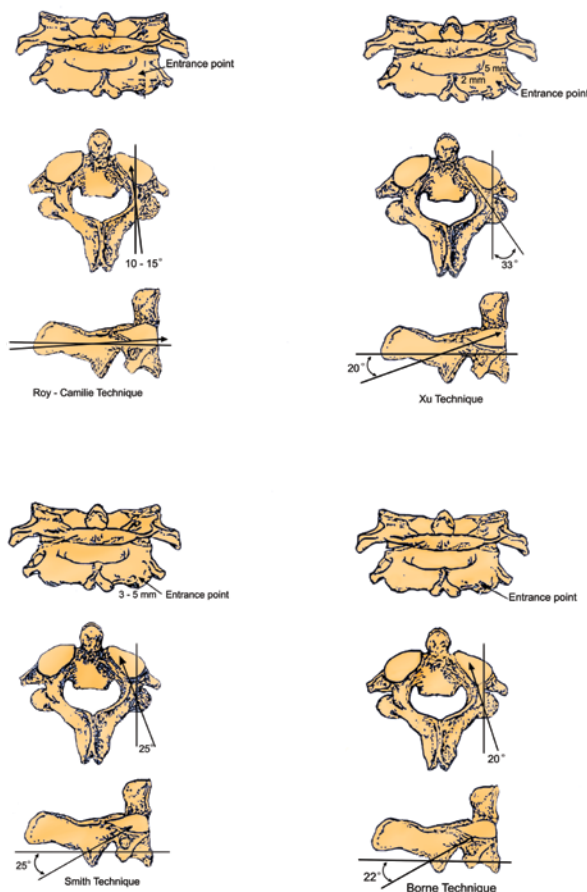


Figure 4. Techniques for screw insertion into C2 pedicle.

the cervical spine appear to be similar to those in the thoracolumbar spine, though data are limited. Pedicle screw fixation in the cervical spine may be an alternative technique for patients who have osteoporotic bones and require multilevel fixation.

TECHNIQUES

Pedicle Screw Placement of the C2 Pedicle

After subperiosteal exposure of the posterior aspect of the upper cervical spine, dissection is extended lateral to the C2–C3 facet joint. The C2 lamina, pedicle, and inferior articular process are further clearly identified using a small curette. Roy-Camille and colleagues¹⁷ recommended that the entrance point for screw insertion be located in the upper medial quarter of the C2 articular mass because the vertebral artery is in front of the 2 lateral quarters and the 1 lower medial quarter (Figure 4). Smith and colleagues⁴ believed that the starting point is 3 to 5 mm superior to the center of the C2–C3 facet joint. After tapping, the screw is directed 10° to 25° medially and 25° cranially, with screw lengths ranging from 20 to 22 mm. Xu and colleagues¹⁸ recommended that the entrance point for screw placement be approximately 5 mm inferior to the superior border of the lamina and 7 mm lateral to the lateral border of the spinal canal. The screw is directed 33° medially and 20° superiorly. For fixation of pedicular fractures of C2, Borne and colleagues³ recommended a precise location of the screw entry on the posterior aspect of the inferior articular process of C2, anatomical reduction of the fractured pedicles, and medial (20°) and cephalad (22°) screw orientation. In their series, they used screws 3.5 mm in diameter and 30 mm in length. Because of individual variation in the C2 pedicle dimension and location of the vertebral artery, C2 pedicle screw insertion must be determined on a case-by-case basis to avoid inadvertent injury to the vertebral artery. Correct identification of the posterior and medial borders of the C2 pedicle and placement of the screws as close as possible to the mediosuperior cortex of the C2 pedicles allow surgeons to avoid penetrating the transverse foramen and damaging the vertebral artery.¹⁹

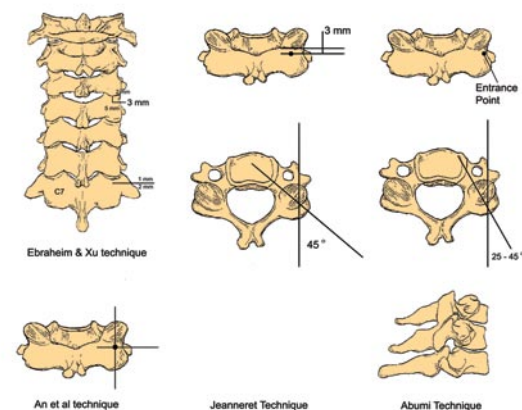


Figure 5. Techniques for screw insertion into lower cervical pedicle.

Pedicle Screw Placement of the Lower Cervical Pedicle

Pedicle screw insertion into the pedicles in the lower cervical spine is a technical challenge that requires a solid knowledge of the 3-dimensional anatomy of the cervical pedicle and experience with pedicle screw fixation in the thoracolumbar spine. Based on the technique described by Abumi and colleagues⁵ and Abumi and Kaneda,²⁰ pedicle screw fixation in the lower cervical spine is performed under fluoroscopy. After exposure of the lateral margin of the lateral masses at the levels to be instrumented, the entrance point for screw insertion is determined. This point is located just lateral

ommended partial laminectomy or laminoforaminotomy before initiation of screw insertion. Pedicle screw insertion guided by direct visualization of the medial, superior, and inferior walls of the pedicle in the lower cervical spine through a partial laminectomy decreases the incidence of screw penetration of the pedicle.

CLINICAL EXPERIENCE

There are few clinical data on patients treated with pedicle screw fixation, but several pedicle screw insertion techniques have been reported. Occipitocervical, cervical, and cervicothoracic instability caused by trauma, degenerative disorders, rheumatoid arthritis,

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to the midpoint of the lateral mass and slightly inferior to the inferior border of the superior facet (Figure 5). The dorsal cortex at the entrance point is penetrated with a burr, and the entrance hole is enlarged. A nerve probe or small curette is used to palpate the inner wall of the pedicle cavity, which is then tapped. Pedicle probing and tapping are monitored with lateral fluoroscopy. Screw direction is 25° to 45° medial in the transverse plane and parallel to the superior endplate of the vertebral body in the sagittal plane based on the measurements of preoperative computed tomography (CT) scans. Available screw diameters are 3.5, 4.0, and 4.5 mm, and lengths are 20, 22, 24, and 28 mm.

To avoid violation of the facet joint, Jeanneret and colleagues⁶ recommended that the entrance point for screw insertion be in the middle of the articular mass and 3 mm beneath the superior facet, with the screw directed 45° medially in the transverse plane. A 4.0-mm cancellous screw can be inserted in the pedicle in the lower cervical spine. Maximal screw lengths are 26 mm at C3–C4, 28 mm at C5, 30 mm at C6, and 32 mm at C7. Based on anatomical studies, Xu and colleagues¹⁰ and Ebraheim and colleagues¹¹ suggested that the screw entrance point for screw insertion at the levels of C3–C6 is approximately 2 mm below the inferior edge of the superior facet and 5 to 6 mm medial to the lateral edge of the lateral mass. At C7, this point lies 1 mm inferior to the midline of the transverse process and 2 to 3 mm medial to the lateral edge of the lateral mass. An and colleagues²¹ documented that the screw entrance point at C7 is at the intersection of the transverse line through the middle of the transverse process and the vertical line through the middle of the facet joint.

Because of the small size of the lower cervical pedicle and the difficulty in determining the accurate starting point and direction for screw insertion, Miller and colleagues²² and Albert and colleagues²³ both rec-

and tumor treatment are the reported indications for pedicle screw fixation in the cervical spine.

Leconte¹ and Roy-Camille and colleagues¹⁷ reported that screws could be successfully inserted into the C2 pedicle to treat pedicular fractures of C2, but they did not provide any clinical data. Borne and colleagues³ reported on 13 patients with pedicular fractures of the axis treated with posterior bilateral pedicle screw fixation with or without C2–C3 wiring. All patients were immobilized with a rigid collar for 3 months after surgery, and all showed excellent results in terms of solid union of the fractures and recovery of the motion of the cervical spine. Smith and colleagues⁴ described 14 patients with significant occipitocervical instability caused by trauma, rheumatoid arthritis, and congenital malformations managed with posterior occipitocervical plating. Screws were inserted into the pedicles at C2 and the lateral masses at the levels below C2. After a mean follow-up of 12 months, all patients were found to have solid fusion between the occiput and C2.

In the lower cervical spine, Jeanneret and colleagues⁶ reported on 3 patients who sustained articular mass fracture-separations and were treated with open reduction and pedicle screw fixation. Fracture levels were between C4 and C6. At follow-up 6 to 8 years after surgery, all fractures healed, 3 patients were pain-free, and no restriction of cervical motion was noted. Abumi and colleagues⁵ documented 13 patients with traumatic lesions of the lower cervical spine. Types of injury included distractive flexion injury, compressive extension injury, and vertical compression injury. Among the 13 patients, a complete neurologic injury was found in 3 patients, and an incomplete injury was found in 5 patients. All patients were treated with pedicle screw fixation using the Steffee VSP system (Acromed, Cleveland, Ohio) and bone grafting. Mean surgical time was 145 minutes, and mean intraopera-

tive blood loss was 283 mL. Postoperatively, patients were immobilized with a soft collar. A solid fusion was achieved in all patients without losing correction of the kyphosis. In another paper, Abumi and Kaneda²⁰ reported on the data of 45 patients with nontraumatic lesions of the cervical spine treated with pedicle screw fixation. The surgical indications involved vertebral and spinal cord tumors, degenerative disorders, rheumatoid arthritis, and infectious diseases. Postoperative follow-up showed that all patients had solid fusion, except those with metastatic vertebral tumors.

In cases of multilevel instability involving the cervicothoracic junction, posterior plating with screws placed into the lateral masses at the C3–C6 levels and the pedicles at C7 and T1 can be considered. Albert and colleagues²³ reported on 21 patients who underwent posterior screw fixation for reconstruction of complex cervical disorders. The C7 pedicle was used as a screw anchor in all patients. At minimum 1-year follow-up, no hardware failure or complication related to pedicle screw fixation was found.

reported by Smith and colleagues,⁴ Jeanneret and colleagues,⁶ and Albert and colleagues²³ in their small clinical series. However, pedicle perforation or penetration by a misdirected or misplaced screw does occur. Abumi and colleagues⁵ evaluated postoperative CT scans from patients who underwent pedicle screw fixation of the lower cervical spine. In 2 patients, 3 pedicles were found to be perforated medially by the screw threads, and a fourth was violated inferiorly. There were no neurologic consequences. In their other series, Abumi and Kaneda²⁰ found that 11 (6%) of 183 pedicle screws penetrated the pedicles. Only 1 patient developed post-surgical radiculopathy, which resolved spontaneously.

SUMMARY

Pedicle screw insertion into the C2 pedicle for occipitocervical plating has become an accepted technique, as it provides stronger fixation with less risk to adjacent neurovascular structures. Because the lateral mass at C7 is thinner, and rigid fixation may not be

“Pedicle screw fixation in the cervical spine may be an alternative technique for patients who have osteoporotic bones and require multilevel fixation.”

COMPLICATIONS

The major complication associated with pedicle screw fixation in the cervical spine is screw penetration of the pedicle. Experimentally, Ebraheim and colleagues¹⁹ placed 32 screws into the C2 pedicle to assess the safety of pedicle screw fixation of the axis. Six (19%) of the 32 screws were found to penetrate the lateral wall of the C2 pedicle, and 3 of the 6 placed the vertebral artery at high risk for injury. However, incidence of pedicle penetration was significantly lower when screw placement was guided by direct visualization of the medial and superior borders of the individual pedicle. Jeanneret and colleagues⁶ inserted 33 screws into the lower cervical pedicles in cadaveric specimens after evaluation of CT scans. Examination of the pedicles showed that there were 10 (30%) minor violations of the pedicle cortex, including 5 in the lateral cortex and 3 in the superior cortex. Miller and colleagues²² found the incidence of pedicle violations to be 47% with blind screw placement versus 25% with screw placement after laminotomy in the lower cervical spine. The highest percentage of violation was found in the medial wall of the pedicle, followed by the lateral wall. In a similar study, in which screws were inserted into the cervical pedicles from C2 to C7 under direct visualization of a single vertebra, Jones and colleagues¹⁶ noted 7 pedicle wall violations (13%), 6 medial and 1 lateral.

Incidence of pedicle violation seems to be higher theoretically than actually. No anatomical complications associated with pedicle screw insertion were

achieved by lateral mass screw fixation, pedicle screw fixation at C7 and lateral mass screw fixation at the levels above have been recommended. Pedicle screw fixation in the lower cervical spine is a new technique that provides an alternative to lateral mass screw fixation. The biomechanical advantages of pedicle screw fixation in the cervical spine are obvious, but data are limited. However, the safety and role of pedicle screw fixation in reconstruction in the lower cervical spine have not been defined. At present, pedicle screw fixation should not be routinely used at the levels of C3–C6. In cases of multilevel reconstruction, rigid fixation can be obtained with combined conventional anterior and posterior techniques. Pedicle screw fixation may be indicated in patients with osteoporotic bone or when rigid internal fixation cannot be achieved with conventional techniques.

AUTHORS' DISCLOSURE STATEMENT AND ACKNOWLEDGMENTS

The authors report no actual or potential conflicts of interest in relation to this article.

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COMMENTARY

The authors must be commended for tackling such a challenging task, and before further comment, I must acknowledge that there is a need for more rigorous criteria for selecting patients for a spine fusion.

A further step toward validating any classification should be to clearly define each of the selection criteria. It is usual to read that surgical treatment was discussed and indicated after unsuccessful attempts at nonsurgical management; however, which clinical symptoms were addressed, which diagnosis was first made, and which nonsurgical treatments were used are rarely described. Moreover, the terms used rarely carry the same meaning from one case to the next. There is an obvious confusion about the term “instability,” and although the terms “stenosis” or “deformity” may look unequivocal, the ways in which they are assessed and understood by different physicians treating spinal problems differ. Both spine surgeons with neurosurgical training and those with orthopedic training and also spine radiologists must seriously commit time and resources to establish a clear, accepted definition for each “key word” used in the diagnoses and radiographic reports.

The natural history of the degenerative spine could be revisited in light of the outstanding work of Wolfgang Rauschnig, MD, PhD.¹ His many contributions can shed light on the natural evolution toward ankylosis and the accidents of instability and mechanical stenosis along the road. I agree with the authors about the need for a refined “nomenclature” and “classification,” which can only be achieved by means of a consensus on the definition of each key word.

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Erratum

Misspelling of Author’s Name: In the article entitled “Back Pain Caused by Benign Tumors and Tumor-like Lesions of the Thoracolumbar Spine,” by Kostas JP, Dailianna Z, Xenakis T, Beris AE, Kitsoulis P, Arnaoutoglou CM, Soucacos PN, published in *Am J Orthop* 2001;30(1):50-56, the second author’s last name was misspelled. The correct listing for the author is Dailiana Z.