Neurovascular risks of sacral screws with bicortical purchase: an anatomical study

Ipek Ergur · Omer Akcali · Amac Kiray ·
Can Kosay · Hamid Tayefi

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Abstract The aim of this cadaver study is to define the anatomic structures on anterior sacrum, which are under the risk of injury during bicortical screw application to the S1 and S2 pedicles. Thirty formaldehyde-preserved human male cadavers were studied. Posterior midline incision was performed, and soft tissues and muscles were dissected from the posterior part of the lumbosacral region. A 6 mm pedicle screw was inserted between the superior facet of S1 and the S1 foramen. The entry point of the S2 pedicle screw was located between S1 and S2 foramina. S1 and S2 screws were placed on both right and the left sides of all cadavers. Then, all cadavers were turned into supine position. All abdominal and pelvic organs were moved away and carefully observed for any injury. The tips of the sacral screws were marked and the relations with the anatomic structures were defined. The position of the sacral screws relative to the middle and lateral sacral arteries and veins, and the sacral sympathetic trunk were measured. There was no injury to the visceral organs. In four cases, S1 screw tip was in direct contact with middle sacral artery. In two cases, S1 screw tip was in direct contact with middle sacral vein. It was observed that the S1 screw tips were in close proximity to sacral sympathetic trunk on both right and

the left sides. The tip of the S2 screw was in contact with middle sacral artery on the left side only in one case. It is found that the tip of the S2 screw was closely located with the middle sacral vein in two cases. The tip of the S2 pedicle screw was in contact with the sacral sympathetic trunk in eight cases on the right side and seven cases on the left side. Lateral sacral vein was also observed to be disturbed by the S1 and S2 screws. As a conclusion, anterior cortical penetration during sacral screw insertion carries a risk of neurovascular injury. The risk of sacral sympathetic trunk and minor vascular structures together with the major neurovascular structures and viscera should be kept in mind.

Keywords Sacral screw · Spine surgery · Anatomy · Complication

Introduction

Lumbosacral fixation still is the most preferred method in the treatment of all forms of lumbosacral instability such as spondylolisthesis, low lumbar fractures, vertebral metastatic tumours, infection, and paralytic scoliosis. Posterior pedicle screw applications to the sacrum are the gold standard for lumbosacral fixation. Multiple techniques have been described for sacral pedicle screw fixation posteriorly, including anterior, antero-lateral, anteromedial, and bicortical fixation through the S1 end-plate [3, 7, 13–15, 17]. S2 screw applications are generally preferred for sacral block fixations and insertion of the screw through the S2 pedicle is almost always the preferred technique [15].

More implant failures and complications are encountered as the number of sacral screw applications

I. Ergur · A. Kiray · H. Tayefi
Department of Anatomy, School of Medicine,
Dokuz Eylul University, Izmir, Turkey

O. Akcali (✉) · C. Kosay
Department of Orthopedics and Traumatology,
School of Medicine, Dokuz Eylul University, Korutürk Mh.
Lodos Sk. Yorgancıoğlu Sitesi, 9/C Blok, K:1 D:3,
Balcova, 35330 Izmir, Turkey
e-mail: omer.akcali@deu.edu.tr

increase. The failure of sacral screw fixation may result from several factors, such as inadequate sacral bone purchase, inappropriate direction of the screw or depth of the screw insertion, osteoporotic sacral bone stock, or a large load resulting from a long fusion lever arm above the sacrum [11]. Various biomechanical studies on the sacral screw insertion angles or different insertion techniques have been performed to avoid these problems [8, 9, 18, 20]. Bicortical purchase of the anterior sacral cortex adds additional biomechanical benefit to the lumbosacral construct [10, 11, 15, 20]. However, anterior sacral penetration of the screw and drilling the anterior sacral cortex carries additional risk of neurovascular injury. Therefore, a thorough knowledge of the anterior sacral structures is important. A number of cadaver and radiological studies have been performed to define safe anatomic landmarks and zones for insertion of S1 and S2 pedicle screws [1, 5, 12, 15, 16, 19]. However, complications especially vascular injuries due to perforation of the anterior sacral cortex are still a challenging subject clinically.

The aim of this cadaver study is to define the anatomic structures on anterior sacrum that are under the risk of injury during bicortical screw application to S1 and S2 pedicles.

Materials and method

Thirty formaldehyde-preserved human male cadavers were studied. All cadavers were placed in prone position. Posterior midline incision was performed, and soft tissues and muscles were dissected from the posterior part of the lumbosacral region. L5-S1 facet joint and posterior aspects of the S1 and S2 foramina were identified. All pedicle screw insertions were performed by the same spinal surgeon (CK). A 3.2 mm drill hole was placed between the superior facet of S1 and the S1 foramen. The drill was positioned as perpendicular to posterior cortical surface of the sacrum and angled approximately, 10° medially. S1 screw hole was prepared with drill bit and anterior cortex was penetrated only a few millimeters. The length of the hole was measured. A pedicle screw in 6 mm diameter and in proper length was placed into the hole and anterior cortex of the sacrum was purchased only in one or two threads.

The entry point of the S2 pedicle screw was located between S1 and S2 foramina. Posterior and anterior cortex was penetrated with 3.2 mm drill bit and the S2 screw was placed perpendicular to the posterior surface of the sacrum.

S1 and S2 screws were placed on both right and left sides of all cadavers.

Then, all cadavers were turned into supine position. All abdominal and pelvic organs were moved away and carefully observed for any injury. The anatomic structures anterior to the sacrum were then carefully dissected. All vascular and neural tissues were identified and the normal anatomic relationships were preserved. The tips of the sacral screws were marked and the relations with the anatomic structures were defined.

The distances between the aorta and vena cava inferior bifurcations and promontorium and S1 screw tip were measured. The midpoint of the anterior edge of the S1 superior end plate was defined as promontorium. The locations of the middle sacral artery and vein according to the midline were recorded. The position of the sacral screws relative to the middle and lateral sacral arteries and veins, and sacral sympathetic trunk were measured. All measurements were done with a fine caliper accurate to 0.1 mm.

Results

There was no injury to visceral organs. Congenital or anatomic lumbosacral osseous anomalies were not observed. The bifurcation points of both aorta and the inferior vena cava were superiorly located from the promontorium in all cases. The mean distance between promontorium and aortic bifurcation was 62.0 ± 13.1 mm, and the mean distance between promontorium and inferior vena cava bifurcation was 39.4 ± 10.6 mm. Normal topographic relationships of the neurovascular structures are shown in Fig. 1.

All S1 screw tips were observed to be located inferior to promontorium. The distance between promontorium and the tip of the S1 pedicle screw on the right and the left side was 13.3 ± 7.8 and 15.0 ± 6.8 mm, respectively. There were no penetration of inferior vena cava, aorta, iliac arteries, and veins by the S1 screws.

In three cases, middle sacral artery was located on the midline of the sacrum and in six cases it was located on the right side. Middle sacral artery was located on the left side in the remaining twenty-one cases. The average distance of middle sacral artery to the midline was 5.5 ± 4.5 mm. In four cases (two on right, two on left), S1 screw tip was in direct contact with middle sacral artery. Middle sacral vein was generally seated with the middle sacral artery; however, in some cases it was found that the vein was placed in a different location than the artery. In four cases, the vein was located on the midline. The middle sacral vein was

Fig. 1 Normal topographic relationships of the neurovascular structures at the anterior part of the lumbosacral junction (*MSA* middle sacral artery, *MSV* middle sacral vein, *LSA* lateral sacral artery, *LSV* lateral sacral vein, *SST* sacral sympathetic trunk)

found on the right side in 10 cases, and on the left side in 16 cases. The mean distance of middle sacral vein to the midline was 6.9 ± 4.6 mm. In two cases (one on right, one on left), S1 screw tip was in direct contact with middle sacral vein (Fig. 2). Lateral sacral artery and vein were located on the far lateral side of the S1 screw tips. S1 screw tip was not in contact with lateral sacral artery in any cases.

It was observed that S1 screw tips were in close proximity to sacral sympathetic trunk on both right and left sides. In 12 cases (six on right, six on left), S1 screw

Fig. 2 The relationship of the S1 and S2 screw tips with the middle sacral artery and vein. The screw tips were in contact with middle sacral artery and vein (*tS1* tip of S1 screw, *tS2* tip of S2 screw, *MSA* middle sacral artery, *MSV* middle sacral vein)

tip was in direct contact with sacral sympathetic trunk (Fig. 3).

The mean distance between the tip of the S2 pedicle screw and the middle sacral artery on the right and left side was 16.7 ± 8.8 and 14.4 ± 8.5 mm, respectively. The tip of the S2 screw was in contact with middle sacral artery on the left side only in one case. However, it is found that the tip of the S2 screw was closely located with the middle sacral vein in two cases.

The tip of the S2 pedicle screw was in contact with the sacral sympathetic trunk in eight cases on the right side. On the left side, the tip of the screw contacted with the trunk in seven cases (Fig. 3). Bilateral contact with the sacral sympathetic trunk was not observed in any case.

Lateral sacral artery was pushed aside by S2 screw tip in three cases on the left, and two cases on the right. In two cases on the left side, lateral sacral vein was also observed to be disturbed by the screws. In four cases, screw tips were in contact with lateral sacral vein.

The details of measurements are given in Table 1.

Discussion

Lumbosacral fusion is the most preferred treatment method in lumbosacral instability or deformities. The main problem with this type of treatment is the difficulty of obtaining a high rate of solid fusion. A stable internal fixation of the lumbosacral junction associated with the posterior or posterolateral grafting may improve the rate of successful solid fusion [17]. At the

Fig. 3 Position of the S1 and S2 screw tips according to the sacral sympathetic trunk. The trunk was pushed anteriorly by the tip of the screws (*tS1* tip of S1 screw, *tS2* tip of S2 screw, *MSA* middle sacral artery, *IIA* internal iliac artery, *SST* sacral sympathetic trunk)

Table 1 The table shows the mean values of distances between anatomic structures anterior to the sacrum and the tip of the S1 and S2 screws

	S1 screw tip (right side) (mm $\pm$ SD)	S1 screw tip (left side) (mm $\pm$ SD)	S2 screw tip (right side) (mm $\pm$ SD)	S2 screw tip (left side) (mm $\pm$ SD)
Middle sacral artery	18.5 $\pm$ 7.9	13.3 $\pm$ 8.4	16.7 $\pm$ 8.8	14.4 $\pm$ 8.5
Middle sacral vein	16.8 $\pm$ 8.6	13.4 $\pm$ 9.6	15.7 $\pm$ 9.1	14.6 $\pm$ 9.5
Lateral sacral artery	9.2 $\pm$ 3.8	8.9 $\pm$ 4.6	7.5 $\pm$ 6.9	8.6 $\pm$ 8.3
Lateral sacral vein	8.6 $\pm$ 6.6	6.6 $\pm$ 4.3	8.3 $\pm$ 6.7	5.2 $\pm$ 4.4
Autonomic sacral plexus	2.5 $\pm$ 3.1	3.2 $\pm$ 3	1.2 $\pm$ 2.1	1.4 $\pm$ 1.8

same time, posterior fixation of the lumbosacral junction may facilitate postoperative rehabilitation and ambulation.

A variety of techniques have been described for lumbosacral fixation [10–14, 16, 17, 20]. Sacral screw fixation is a gold standard for sacral bone purchase. Sacral screws can be placed anteromedially through the S1 pedicle into the promontory or anterolaterally into the sacral ala [11]. Anteromedial route for sacral purchase is more commonly preferred technique for sacral fixation. Major vascular structures such as iliac vessels are localized at anterior and lateral part of the sacrum. In addition, the lumbosacral trunk is placed at the anterolateral surface of the sacrum. Thus, the risk of neurovascular injury is more likely at the anterolateral side than the anteromedial side if the screw penetrates the anterior cortex. However, the risk of excessive anteromedial angulation is penetration of the spinal canal.

Krag et al. [8] and Roy-Camille et al. [17] strongly recommended avoiding anterior cortex penetration because of the risk of neurovascular injury. However, it is biomechanically shown that the bicortical screw purchase to the sacrum increases the pull-out strength [20]. The sacrum mainly consists of cancellous bone, and the lumbosacral junction generally resists the shear forces. For that reason, rigid screw fixation to the sacrum may play an important role to achieve a rigid lumbosacral fusion. Triangulated insertions of the sacral screws [18], fixation through the promontorium [14], different types of sacral blocks, or bone purchase with multiple screws were proposed in the literature [8, 9, 11, 20]. The surgeon decides on the technique of insertion which all have different rate of injury to neurovascular structures.

Many spine surgeons are not familiar to anterior sacral anatomy. Lumbosacral fixations generally are achieved posteriorly. Injuries of anatomic structures anterior to the sacrum can lead to hemorrhage, neurologic deficit, or chronic pain [3, 6]. It is of utmost importance to know the localizations of anatomic structures at risk and their relationships with implants.

Mirkovic et al. [15] performed a study to define the neurovascular and visceral anatomy anterior to the sacrum as it pertains to sacral screw placement. They investigated the possible incidence and pattern of injury to anatomic structures. They defined two safe zones for S1 screw placement, one medial and one lateral. Medial safe zone lies between the sacral promontory medially and the internal iliac vein laterally. Screws placed in the S1 pedicle invariably entered the medial safe zone. This technique was advocated because of the minimal risk of neurovascular injury. In our study, all screws are applied through the S1 pedicle and the tips of the screws are located in the medial safe zone. However, it is found that the tips of the S1 screws were localized very close to the neurovascular bundle. We found that the sacral sympathetic trunk particularly was in risk of injury in 40% of cases. Mirkovic did not report any ratio regarding the middle sacral artery or sacral sympathetic trunk.

Esses et al. [5] studied the anterior sacral anatomy to allow safe sacral screw placement. They used a computerized tomography scan individually to detect the safest route. They reported that a screw starting above and in line with the first sacral foramen, directed medially and parallel to the upper surface of the sacrum, would be safe. However, they suggested that the S1 screw might injure the middle sacral artery and vein. Because of this, they did not suggest the anterior cortical penetration. If sacral screws do not provide adequate fixation, they recommended the anterior lumbosacral fusion. In our study, our sacral screw application technique is so similar with the Esses et al. Furthermore, risk of injury to sacral sympathetic trunk was observed as well as risk of injury to vascular structures in our study. The study of Esses et al. [5] was not performed on cases with fixation and rate of injury was not reported.

Licht et al. [12] performed a study to evaluate the structures anterior to the sacrum that were at risk of injury when pedicle screws were used. In their study, K wires were placed into the S1, S2, and S3 vertebrae with in two different technique and the relationships

between the tip of the K wires and anatomic structures were evaluated. They found that the common iliac artery and vein, and sympathetic chain are at high risk when S1 screws were inserted with direct transpedicular technique. They did not define any risk of middle sacral artery at the same level. In our study, injuries of the major vascular structures such as iliac vessels were not detected because the tips of the screws were clearly localized at the inferior levels. The middle sacral artery was at risk both on the right and the left side. The main reason of differences of these two studies may be the number of the specimens. In the study of Licht et al., only five cadavers were dissected. For this reason, series with higher numbers of specimens may help delineate the anatomical structures at risk.

A few anatomic studies have been published in English literature to define the exact location of the safe sacral screw purchase [1, 2, 4, 5, 12, 15, 16, 19]. Ebraheim et al. [1] investigated the length and entry angle of the S2 screw for lumbosacral fixation. They defined the proper screw length and suggested that the higher lateral angulation than the perpendicular insertion of S2 sacral screws would decrease the possibility of violence to the anterior neurovascular structures. In addition, some authors advocated the use of lateral mass screws in case of S2 to avoid anterior neurovascular injuries [1, 4].

In this study, sacral screws were inserted with the same surgical technique used in surgeries by the surgeons. The tip of the sacral screws penetrated the anterior cortex only by one or two threads. No major vascular injury was detected in this study. However, middle sacral artery and vein and sacral sympathetic trunk were found to be at risk of injury by the sacral transpedicular screws. The clinical significance of cadaveric studies can be limited. Injuries of minor neurovascular structures may sometimes be asymptomatic and undetected clinically. However, every effort must be shown to decrease the complications related to bicortical screw placement at sacrum.

As a conclusion, anterior cortical penetration during sacral screw insertion carries a risk of neurovascular injury. The risk of sacral sympathetic trunk and minor vascular structures together with the major neurovascular structures and viscera should be kept in mind.

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