Ventral abdominal approach for screw fixation of sacroiliac luxation in cadavers of cats and dogs

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Objective—To investigate a technique for repair of sacroiliac luxation with positional screw insertion from the ventral surface of the sacral wing via a ventral abdominal approach.

Sample Population—Hemipelvis specimens from cadavers of 5 small- to large-breed dogs and 9 European shorthair cats.

Procedures—An optimal entry point and a safe drill corridor for implant placement were determined (4 hemipelvis specimens). Anatomic landmarks were identified, and the surgical technique for a ventral abdominal approach was described. Single positional screw placement was performed across the sacroiliac joint in 23 hemipelvis specimens. Screws were aimed at 25° (n = 2), 35° (2), and 45° (19) angles to the vertical axis in a transverse plane (α angles) and at a 90° angle to the longitudinal axis in a dorsal plane (β angle). Implant placement was assessed by radiographic evaluation of the cadavers and of the hemipelvis specimens devoid of soft tissue.

Results—By use of α angles of 35° and 45°, 20 of 21 implants were placed adequately; screws crossed the sacroiliac joint and penetrated the wing of the ilium without damaging adjacent nerves. The measured median α angle was 38°, and the median β angle was 88°. One complication was recorded.

Conclusions and Clinical Relevance—Cortical positional screw placement from the ventral aspect of the sacral wing by use of a ventral abdominal approach could be an alternative to conventional techniques. This novel technique may be useful for repair of bilateral sacroiliac luxation, treatment of concomitant soft tissue injuries of the caudal portion of the abdominal cavity or abdominal wall, and repair of pelvic floor fractures in a single approach. (Am J Vet Res 2008;69:542–548)

Unilateral or bilateral sacroiliac luxation is a common injury in cats and dogs and accounts for 27% of all pelvic fractures in cats1 and 21% in dogs.2 In many instances, sacroiliac luxation is the result of road traffic accidents, and patients usually have concomitant soft tissue or orthopedic injury, particularly to the thorax, caudal portion of the abdomen, and pelvic region. The combination of unilateral or bilateral sacroiliac luxation and pelvic floor fractures is seen in 15% of dogs and 22% of cats with pelvic trauma.1,3–4 The incidence of concurrent trauma to the urinary tract has been reported to be as high as 40%.5 In 1 study,6 peripheral nerve injuries occurred in 11% of pelvic fractures; 54% of these were attributable to injuries of the intrapelvic portion of the sciatic nerve.

Treatment options of sacroiliac luxation include conservative management or surgical repair. Indications for surgical stabilization of sacroiliac luxation and pelvic fractures have been described1–9 and include pain and inability to ambulate, neurologic deficits attributable to sacroiliac luxation, marked instability or displacement (> 50%) of 1 or both hemipelvises, pelvic outlet obstruction, and concurrent orthopedic injuries. Soft tissue injuries in the caudal portion of the abdo-

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Abbreviations

<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>OEP</td>
<td>Optimal entry point</td>
</tr>
<tr>
<td>ABmin</td>
<td>Cranial limit of safe exit area</td>
</tr>
<tr>
<td>CDmin</td>
<td>Dorsal limit of safe exit area</td>
</tr>
<tr>
<td>CDmax</td>
<td>Ventral limit of safe exit area</td>
</tr>
<tr>
<td>ABmax</td>
<td>Caudal limit of safe exit area</td>
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<tr>
<td>TEP</td>
<td>True entry point</td>
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men or pelvic region may also require surgical intervention, although the approach may differ from that used for stabilization of sacroiliac luxation.

Many surgical methods, such as closed surgical repair10 and tension band techniques in cats,11 have been described. However, open reduction and lag screw placement remains the classic and most frequently used method. A dorsolateral12,13 or ventrolateral approach2 may be used, and variations, such as transsacral screw placement for bilateral sacroiliac luxation stabilization, have been described.11

In a retrospective study12 involving sacroiliac fractures in dogs that were treated with a lateral lag screw, 67% of screws were placed incorrectly by use of a proposed
100° drill angle in a dorsoventral plane was still 23%. In another study, the misplacement risk was reduced to 10% by use of ilial landmarks for screw hole drilling. These 2 studies were conducted on cadavers; therefore, the described implants’ misplacement rates may be different under clinical conditions.

Repair of sacroiliac luxation with lateral screw fixation is still a challenging surgical intervention because vital adjacent structures, especially spinal, lumbar, and sacral nerves, may be damaged during the process, especially in small animals like cats, where the small size of the sacral body makes screw insertion difficult. The purpose of the study reported here was to evaluate the feasibility of a technique for sacroiliac luxation repair by use of single screw insertion from the ventral surface of the sacral wing via a ventral abdominal approach.

Materials and Methods

The study was conducted under a protocol approved by the Department of Small Animal Surgery, Vetsuisse Faculty-Zurich, University of Zurich, Switzerland.

Study population—Cadavers of 9 cats and 5 dogs, which had been euthanatized for reasons unrelated to this study, were used. Consent from the owners was obtained prior to inclusion of cadavers in the study.

For determination of a safe drill corridor, pelvic specimens were procured from 1 Beagle and 1 European shorthair cat (n = 4 hemipelvis specimens) for determination of anatomic landmarks and angle measurements. For investigation of the surgical approach and implant placement, cadavers of 4 dogs (1 Jack Russell Terrier, 1 Shih Tzu, and 2 Labrador Retrievers) and 8 European shorthair cats (n = 24 hemipelvis specimens) were used for the ventral abdominal approach and the bilateral placement of implants. Pelvic specimens of all cadavers were collected, stripped of soft tissue, and dried for subsequent measurements.

Determination of a safe drill corridor—The safe drill corridor was determined bilaterally on pelvic specimens of a Beagle and a European shorthair cat (n = 4 hemipelvis specimens). The OEP for drilling and screw placement was assumed to be on the ventral surface of the sacral wing, lateromedially at the deepest point between the sacroiliac joint and the median of the sacrum, and cranio-caudally at the level of the promontorium of S1 (Figures 1 and 2). This point was marked with a metallic bead.

The safe drill corridor was defined as a 3-dimensional cone-like corridor for safe placement of implants from the ventral surface of the sacral wing through the sacroiliac joint into the ilial wing. The origin point (vertex) of the corridor was the OEP, and the base was defined by the sacral surface of the sacroiliac joint. This surface was limited cranially by the caudal edge of the projection of the sacral wing over the lumbosacral intervertebral space (ie, the ABmin of cranial overlap) and dorsally by the ventral edge of the projection of the sacral wing over the spinal canal (ie, the CDmin of dorsal overlap), as described in a previous study in cats.

Ventrally and caudally, the area was delimited by the dorsal (ie, the CDmax) and cranial (ie, the ABmax) edges of the semilunar cartilage area on a horizontal and vertical line (Figure 3). These limits were marked with metallic beads on both sides of the sacrum and subsequently radiographed orthogonally. The distance from the ventral edge of the sacral wing to the marker of the OEP on the craniocaudal radiographic view was measured and expressed as the percentage of the total distance between the ventral edge of the sacral wing and the median of the sacrum (Figure 1).

The α minimum and α maximum angles were measured between the vertical median (0°) and lines drawn through the OEP and CDmin or CDmax on craniocaudal radiographic views, respectively (Figure 1). The β minimum and β maximum angles were measured on dorsoventral radiographic views between the sagittal midline (0°) ventrodorsal radiographic view and lines drawn through the OEP and ABmin or ABmax, respectively (Figure 2).

Surgical approach—The approach was performed bilaterally in cadavers of 8 cats and 4 dogs (n = 24 hemipelvis specimens). Cadavers were placed in dorsal recumbency with the hind limbs left unbound. A caudal median celiotomy was performed from the umbilicus...
to the pubis. The small intestine and omentum were retracted cranially, and the urinary bladder and the colon were retracted away from the surgeon with Langenbeck retractors. The tendon of the psoas minor muscle and the promontorium of S1 were identified digitally (Figure 4). The retroperitoneum was opened bluntly over the tendon of the psoas minor muscle at the level of the promontorium of S1. The retroperitoneal fat was dissected bluntly until the tendon of the psoas minor muscle was reached. It was crucial to prevent damage to the ureters, external iliac artery and vein, and associated smaller vessels during this procedure. The dissection was continued medially to the tendon of the psoas minor muscle to expose the ventral edge of the sacroiliac joint. At this point, the obturator nerve and the ventral nerve roots originating from L6 and L7 were observed. They were located ventrally and just medially to the sacroiliac joint and were carefully retracted medially with a blunt nerve hook to view the ventral surface of the sacral wing.

**Implant placement**—Drilling from the medial border of the ventral surface of the sacral wing across the sacroiliac joint into the ilial wing was performed with a 25°, 35°, or 45° angle to the vertical axis in a transverse plane (α angle), as measured during the procedure with the help of a template, and at a 90° angle (β angle) to the longitudinal axis in a dorsal plane. A drill guide was used to protect surrounding soft tissue. Prior to drilling, the position of the cadaver was inspected to ensure that both tuber coxae were at the same level in relation to the table, and therefore both sacral wings were in a horizontal plane. The α angle was targeted at 25° and 35° in 2 specimens each and at 45° in the remaining 19 specimens. Specimens were chosen randomly. The depth of the drill hole was then measured and a cortical self-tapping screw of adequate length was inserted in a positional fashion. The abdomen was closed in 1 layer with 2-0 polyamide suture material in a simple continuous pattern.

By chance, 2 cat cadavers had traumatic sacroiliac luxation and separation of the pelvic symphysis; the sacroiliac luxation was unilateral in 1 cat and bilateral in the other cat. The sacroiliac luxation was reduced prior to screw insertion by manipulation of the hind limbs and the ilial wing by use of Kocher forceps placed on the tuber coxae while both hip joints were held in a flexed position. The sacroiliac joint was then temporarily stabilized with pinpointed reduction forceps positioned across the ilial and sacral wings. After screw insertion, the approach was extended to the pelvic floor by sharp division of the gracilis and adductor muscles to expose and stabilize the pelvic symphysis with a single 0.8-mm cerclage wire.

Lateral, ventrodorsal, and craniocaudal (intrapelvic) radiographic views of the pelvis were obtained to assess screw position. For screw placement, the α angle was measured on craniocaudal radiographic
views and the β angle was measured on ventrodorsal radiographic views (Figure 5).

Implant assessment—Pelvic specimens, once devoid of soft tissues, were positioned to obtain cranio-caudal radiographic views with the beam directed exactly perpendicular to the screw. The α angle was then measured on the radiographs (Figure 6). Implants were removed and the sacrum separated from the remaining pelvis. Markers were placed on both sides of the sacrum, radiographs were obtained, and measurements done as already described. Additionally, the TEP of implants obtained during the procedure was measured in the same manner as the OEP.

Coordinates of the exit point of the screw on the sacral joint surface were measured directly on the bone with a slide caliper and documented. They were expressed as a percentage of the length and height of the sacral joint surface (Figure 3).

Statistical analysis—Median, minimum, and maximum values were calculated. Differences between angle measurements and between values of cats and dogs were analyzed by use of a factorial and repeated ANOVA. Differences between categoric variables were analyzed by use of the Bonferroni-Dunn test. A value of $P < 0.05$ was considered significant.

Results

Determination of a safe drill corridor—Mean ± SD location of the OEP was 58 ± 3% of the total distance between the ventral edge of the sacral wing to the median of the sacrum on the cranio-caudal radiographic view. Mean α minimum and α maximum angles were 36 ± 4° and 85 ± 6°, respectively. Mean β minimum and β maximum angles were 77 ± 6° and 130 ± 14°, respectively.

Surgical approach—Complications were not encountered by use of a ventral abdominal approach. All abdominal structures described were easily identified and accessed.

Implant placement—Twenty-three cortical screws were placed through the sacroiliac joints in 12 cadavers. Screw length ranged from 16 to 18 mm in cats and from 18 to 34 mm in dogs. Screw size ranged from 2.0 to 3.5 mm. Except for 2 specimens in which the targeted α angle was 25°, all screws crossed the sacroiliac joint and penetrated the ilial bone. Median α and β angles for screw placement were measured from radiographs (Table 1). Ninety-five percent (20/21) of screws were placed adequately. In 1 specimen (right hemipelvis of the Shih Tzu), screw placement resulted in a complication in which the ventral edge of the right sacral wing was fractured. The fracture line went through the screw hole, tangential to the ventral edge of the sacral wing, and happened during tightening of the screw. Not enough intact bone was left to place another screw, and therefore, the sacrum could not be fixed to the ilium. Radiographs of both cat cadavers with sacroiliac luxation revealed that the cranio-caudal luxation had been reduced almost completely (93% to 100%) by use of the ventral abdominal approach for repair.

Implant assessment—Minimum, maximum, and median values of angle, TEP, and coordinates of the exit point of screws on the sacroiliac joint surface of all specimens were obtained after the procedure (Table 1). Significant differences were found between targeted α angles and α angles measured on cadavers. Significant differences also were found between targeted α angles and α angles measured on bone specimens. No
significant differences were found between measured α angles on cadavers and α angles measured on bone specimens or between targeted β angles and measured β angles on cadavers. Results of the OEP measurements were significantly greater than the TEP obtained during the procedure. For all variables measured in this study, no significant differences were found between cats and dogs.

Discussion

We investigated a ventral abdominal approach for screw placement from the ventral surface of the sacral wing into the ilial wing across the sacroiliac joint. This approach allowed a good view of the ventral aspect of both sacroiliac joints, the ventral part of the sacral wings, adjacent vessels and nerves, and organs in the caudal portion of the abdomen. It could be used for bilateral sacroiliac luxation fixation via a single approach, allowing concomitant treatment of potential injuries of the abdominal wall and organs in the caudal portion of the abdomen. Extending the approach caudally also allowed for pelvic floor fractures to be reduced and stabilized. For successful use of this new technique, the screw had to be placed at the base of the sacral wing, approximately at a midpoint between the median and the sacral wing edge. It was also necessary to keep the established drill α angle between 36° and 85° relative to the vertical axis to cross the sacroiliac joint and penetrate the ilial wing safely.

Although the surgical anatomy of the sacrum, ilium, and sacroiliac joint has been described in detail for cats and dogs, some of these measurements required for this new technique were not available in the literature. Therefore, angles for a safe drill corridor and the OEP were determined on 4 hemipelvis specimens as a first part of the study.

The OEP at the base of the sacral wing was easy to locate in all cadavers. At this location, the drill hole was situated in sacral bone thick enough to ensure good bone-screw interface. It was important that the implants be placed in a safe drill corridor to avoid exiting through the semilunar joint surface, where the sacral wing bone was thinner. Moreover, it was critical to stay in the safe drill corridor to ensure that they crossed the sacroiliac joint and penetrated the ilial wing without damaging the sacral nerves or entering the vertebral canal or the lumbosacral joint. The base of the cone-shaped corridor on the sacral joint surface was determined in previous anatomic studies of the sacrum in cats and dogs. These studies determined safe drilling areas for lateral screw placement into the sacral body of S1. Mean values of the maximum and minimum drill angles in the dorsovenral and craniocaudal planes measured in 4 specimens were used to determine the range for screw placement in this study. With an α angle < 36°, a risk was found for missing the ilium, exiting the dorsal surface of the sacrum, damaging the dorsal nerve roots of S1, or even entering the vertebral canal. With an α angle > 85°, a risk was found for the screw penetrating the ventral part of the semilunar joint surface; the screw would then be placed too superficially in the sacral wing bone to ensure good fixation. When the β angle was < 77°, a risk was found for the screw exiting into the lumboasacral joint and possibly injuring the ventral nerve root of L7 or ending in the sacral notch in dogs. The risk of the implant penetrating the caudal part of the semilunar joint surface was increased when the angle was > 130°.

An α angle of 45° was chosen for the subsequent part of the study because it was within our safe drill corridor and considered to be an easy angle for the surgeon to estimate. The use of α angles of 25° and 35° in

Table 1—Results of measurements of screw placement across the sacroiliac joint by use of a ventral abdominal approach in cadaver dogs and cats.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Cat specimens (n = 15)</th>
<th>Dog specimens (n = 8)</th>
<th>Total specimens (n = 23)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Med</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>α Angle [*; targeted]</td>
<td>45</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>α Angle [*; bone]</td>
<td>40</td>
<td>6</td>
<td>46</td>
</tr>
<tr>
<td>α Angle min [*]</td>
<td>38</td>
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<td>50</td>
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<tr>
<td>α Angle max [*]</td>
<td>89</td>
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<td>94</td>
</tr>
<tr>
<td>β Angle [*; cadaver]</td>
<td>87</td>
<td>70</td>
<td>114</td>
</tr>
<tr>
<td>β Angle min [*]</td>
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<td>88</td>
</tr>
<tr>
<td>β Angle max [*]</td>
<td>138</td>
<td>118</td>
<td>146</td>
</tr>
<tr>
<td>TEP (%)</td>
<td>40</td>
<td>22.2</td>
<td>57.1</td>
</tr>
<tr>
<td>Distance AX (%)</td>
<td>43.3</td>
<td>37.5</td>
<td>62.5</td>
</tr>
<tr>
<td>Distance ABmin (%)</td>
<td>25</td>
<td>21.4</td>
<td>33.3</td>
</tr>
<tr>
<td>Distance ABmax (%)</td>
<td>68.8</td>
<td>62.5</td>
<td>84.6</td>
</tr>
<tr>
<td>Distance CX (%)</td>
<td>44.5</td>
<td>33.3</td>
<td>57.1</td>
</tr>
<tr>
<td>Distance CDmin (%)</td>
<td>26.6</td>
<td>16.7</td>
<td>33.3</td>
</tr>
<tr>
<td>Distance CDmax (%)</td>
<td>72.4</td>
<td>71.4</td>
<td>80</td>
</tr>
</tbody>
</table>

*Significant (P < 0.05) difference between the median (total) α angle (targeted) and α angle (cadaver).
†Significant (P < 0.05) difference between the median (total) α angle (targeted) and α angle (bone).

α Angles: α angles in the dorsoventral plane that determined the cone-shaped corridor on the sacral joint surface was determined in previous anatomic studies of the sacrum in cats and dogs. These studies determined safe drilling areas for lateral screw placement into the sacral body of S1. Mean values of the maximum and minimum drill angles in the dorsovenral and craniocaudal planes measured in 4 specimens were used to determine the range for screw placement in this study. With an α angle < 36°, a risk was found for missing the ilium, exiting the dorsal surface of the sacrum, damaging the dorsal nerve roots of S1, or even entering the vertebral canal. With an α angle > 85°, a risk was found for the screw penetrating the ventral part of the semilunar joint surface; the screw would then be placed too superficially in the sacral wing bone to ensure good fixation. When the β angle was < 77°, a risk was found for the screw exiting into the lumbar region and possibly injuring the ventral nerve root of L7 or ending in the sacral notch in dogs. The risk of the implant penetrating the caudal part of the semilunar joint surface was increased when the angle was > 130°.

An α angle of 45° was chosen for the subsequent part of the study because it was within our safe drill corridor and considered to be an easy angle for the surgeon to estimate. The use of α angles of 25° and 35° in
a few specimens was only for the purpose of recording where screws exited the sacral bone. A $\beta$ angle of 90° was used in all specimens, was also within the safe drill corridor, and was an easy angle to target during the procedure.

The ventral abdominal approach allowed digital localization of the tendon of the psoas minor muscle and the promontorium of S1. Once the retroperitoneum was accessed, extensive knowledge of the anatomy of the caudal portion of the abdomen was required to avoid damaging the ureters, nerves, and blood vessels. These vital structures, the ventral part of the sacroiliac joints, the ventral side of the sacral wings, and the promontorium were exposed without difficulty in all cadavers. The obturator nerve and ventral nerve roots of L6 and L7 were freed and handled carefully. In all cadavers, the ventral roots of L7 crossed the base of the sacral wings, just over the OEP; but could be carefully retracted either laterally or medially for implant placement.

The main difficulty during drilling was achieving a 45° $\alpha$ angle because of the position of the pelvis and the presence of the bladder, colon, and contralateral abdominal wall, which hindered the oblique angle of the drill. This was particularly true in the 2 Labrador Retrievers because of the deeper location of the sacrum, compared with cats and small dogs. A high degree of retraction and the use of a malleable retractor to push soft tissue down were necessary to adequately position the drill in these animals. From our experience, achieving a 45° $\alpha$ angle is easier in cats and small breed dogs but is technically challenging in dogs with a body weight > 15 kg. Achieving a 90° $\beta$ angle was straightforward. The use of a drill guide was important to protect surrounding soft tissues and to stabilize the drill bit. An oscillating drill mode should be used to provide protection of soft tissue, especially the nerves. No damage to nerves or vessels was observed during or after the procedure. Although functional damage to these structures while applying this new technique is unlikely, it cannot be ruled out. Therefore, further clinical studies on affected animals are needed to provide more information about potential complications caused by this technique.

Sacroiliac fractures were present unilaterally in 1 cat and bilaterally in another. The sacroiliac joint surface of the ilium was clearly exposed and allowed a precise view of its caudal border for subsequent reduction. In both cats, fracture reduction was straightforward and was achieved by manually pushing the free-hanging hind limbs with a caudal flexion in the hip joints and simultaneously grasping the ilium with Kocher forceps at the tuber coxae and pulling it caudally. Once the fracture was reduced, placement of the pinpointed forceps was easy, and the implants were placed in the same way as in the other specimens. Caudal extension of the approach to the pelvic floor in both cat cadavers allowed the repair of a pelvic symphyseal fracture with a single wire cerclage; in our opinion, this has the advantage of preventing rectal or urethral entrapment between the 2 fragments, as reported previously, and adding stability to the pelvic ring. In live animals, the almost perfect cranio- caudal repositioning of the sacroiliac luxation would have provided good stability and most likely allowed a rapid return to ambulation. One cat cadaver also had avulsion of the rectus abdominis muscle, which could have been easily repaired via the ventral abdominal approach.

Screws varied in length depending on the size of the pelvis and the drill angle that was used. An adequate length was crucial for penetration of the second cortex of the ilial bone, thereby ensuring stability. The adequate length was measured during the procedure with a depth gauge. The screw size varied with the size of each pelvis and was chosen preoperatively with help of ventrodorsal radiographic views of the pelvis. The largest possible screw was always used, with a condition that a distance of at least 2 times the screw diameter between sacral wing bone edge and screw hole was respected. We estimated 2.0- to 2.4-mm screws to be adequate for cats, 2.4-mm screws being recommended in adult cats, and 2.0- to 3.5-mm screws for dogs, depending on the size of the dog. In large dogs, a 4.5-mm screw may be used; however, this technique was not applied to large dogs in our study. Whether the screw size would be sufficient in clinical patients for immediate weight bearing has to be evaluated in clinical and biomechanical studies.

On 1 side of the Shih Tzu cadaver, a tangential fracture of the edge of the sacral wing appeared during tightening of a 2.7-mm screw. This fracture running through the screw hole prevented drilling another hole, and it was no longer possible to fix the sacrum to the ilium. The screw was placed at the appropriated entry point, but the placement angle could not be measured after the fracture happened. The fracture most likely occurred because of the excessive size of the implant, compared with the size of the sacrum wing bone. In a clinical setting, this complication could be solved by placement of a screw through a standard lateral approach or placement of a locking plate ventrally between the ilium and sacrum.

Some difficulty was encountered during the procedure while entering the OEP; because of the steep drill angle, the drill tended to slide laterally. This produced a lateral shift of the measured TEPs, as evidenced by a median value of 38% instead of the targeted 58% of the OEPs. This difference represented a real shift laterally of only 1 to 3 mm and would be unlikely to influence the holding power of the implant. Drilling through the cortex of the sacrum was modified during the study; the drill was aimed first in a vertical direction until penetration of the first sacral cortex and then at the targeted 45° angle. This change improved the drill precision for the OEP by protecting the tendency to shift laterally.

The radiographic screw position and angle assessment on whole cadavers were analyzed and compared with the radiographic assessment of prepared pelvic specimens of the same cadavers. The median value of the $\alpha$ angle obtained from the radiographs of cadavers was significantly less than the targeted angle. This is thought to reflect a tendency of the drill to move vertically into the bone, explained by the difficulty in ensuring that both sacral wings were positioned on a horizontal line and by soft tissue hindering the oblique position of the drill.

The median value of the $\alpha$ angle in the prepared specimens was also significantly less than that of the
targeted angle but not different from the angles measured on the radiographs of cadavers. From this it can be concluded that the use of craniocaudal radiographic views of the cadavers was useful for measuring the \( \alpha \) angle of implants. Except for 2 screws that were aimed at a 25° angle, all implants were placed across the sacroiliac joint into the ilial bone. The median \( \alpha \) angle of these implants, which was between the median values of the \( \alpha \) minimum and \( \alpha \) maximum angles, confirmed that screws can be accurately placed provided that the drill angle of implants remains within the safe drill corridor.

The median \( \beta \) angle of implants was close to the targeted 90°. Moreover, this value was also within the range provided by the median values of the \( \beta \) minimum and \( \beta \) maximum angles and indicated that the implants had a correct angle in the craniocaudal plane as well.

The coordinates of the exit point of implants on the sacral surface of the sacroiliac joint were used to assess the proper placement of implants and to ensure that they did not exit outside the safe area and damage adjacent structures. The median distances of the length and height of the sacral joint surface were within the ranges formed by the median distance between ABmin and ABmax and by the median distance between CDmin and CDmax. Again, except for the 2 screws placed at a 25° \( \alpha \) angle, all implants exited within the safe area. Implants did not damage the semilunar cartilage surface and were at a safe distance from the sacral nerves, lumbosacral joint, and vertebral canal.

References