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Anatomical considerations of safe drilling corridor upper sacral segment screw insertion

Hassan Bagheri, Figen Govsa*

Department of Anatomy Digital Imaging and 3D Modelling Laboratory, Faculty of Medicine, Ege University, Izmir, Turkey

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ABSTRACT

The upper segment of sacrum is an important for screw insertions of unstable lumbosacral spine. Measurements of the S1–S2 as sacral wings, pedicles, sacral foraminas and sacral canal were taken from 87 sacrums. The mean depths of S1 pedicle and sacral wing were estimated as 25.8 ± 2.3 mm and 50.1 ± 1.7 mm, respectively. Angles screw trajectory of sacral pedicle anteromedial and sacral wing were measured as 29.6 ± 0.9° and 29.7 ± 2.1°, respectively. To avoid injury to the vascular structures anteriorly and nerve roots medially, depth and angle of screw trajectory is important for the entrance off pedicular screw placement to the S1.

1. Introduction

The unstable lumbosacral spine is most commonly associated with fractures resulting from traumatic (high-energy injuries such as fall from height or motor vehicle accidents) or insufficient-osteoporosis or metastatic sacral infiltrations.[1–4] Sacral fractures have been identified with fracture lines, foraminal step ladder sign, and disruption of the anterior superior sacral foraminal lines or sacral arcuate line as diagnostic clues.[1,4–6] The presence of two vertical fracture lines through the sacral foramina with a transverse fracture line separates the upper and the lower sacral segments (S1 and S2, or S2 and S3). Sacral fracture lines involve one or more sacral foramina and extend medial to the sacral canal with a much higher risk of injury to the sacral nerve roots and cauda equina.[7–9]

Sacral transpedicular instrumentation have been widely used for the treatment of unstable lumbar spine disorders, including trauma, degenerative conditions, spondylolisthesis, neoplasms, congenital defects, extensive laminectomies spinal disorders, lumbar scoliosis for metastatic, infectious, degenerative and traumatic diseases affecting the sacrum.[7,10–17] To avoid failures and to achieve successful spinosacral or spinopelvic instrumentation, numerous studies have reported S1 screws, alar screws and iliac screws.[7,13,14] Most of these techniques have drawbacks including surgical difficulties, complications, insufficient fixations, implant prominence and soft damages.[20,21] Due to the complex anatomy of the upper sacrum and high variability amongst individuals, sacroiliac screw placement is still a challenge for the surgeons.[6,8,10,14,22,23] Safe and strong biomechanical stability is affected by several factors all of which have been studied extensively by many authors, such as projection of lumbar pedicle, cortical and cancellous diameter of pedicle, poor-bone quality and variational anatomy of the sacrum.[11,24–26]

Various optimal entry points and optimal trajectory insertions have been previously investigated in anatomic studies using cadavers or CT images.[18,21,27,28] Bicortical screw should also be penetrated sacrum anteriorly into the safe zone (which is around sacral promontory), to avoid injury to the vital anterior sacral structures such as the internal iliac vein and the artery.[7,10,15,17,29,30] The main risk is the possibility of generating a conflict with the S1 roots in their sacral foramina. Therefore, to achieve the strongest biomechanical stability and to avoid injury, it is crucial to determine the optimum screw length for each individual surgery in anteromedial S1 screw insertion.

Numerous authors have already assessed the anatomy of the upper sacral bones including sacral pedicles, S1 foramina and sacral bone density.[3,6,29–31] If the S1 vertebra is inadequate for the screw placement, screws can be inserted into the S2 sacral wing or the vertebral body to stabilize the lumbosacral junction.[7,8,15,22,24,28,31–33] The objective of this study was to assess the anatomical variability of the adult upper sacrum and to provide a user guide for optimal screw placement to the S1 and S2 vertebra for transpedicular fixation.

The aims of this study are

1. To analyze the anatomy of the upper sacrum as screw extends through the S1 and S2 vertebral body.
2. To determine the presence, dimensions and borders of a safe zone osseous corridor through which a transpedicular screw can be placed across S1 or S2.

* Corresponding author. Department of Anatomy Digital Imaging and 3D Modelling Laboratory, Faculty of Medicine, Ege University, TR-35100, Izmir, Turkey.
E-mail addresses: figen.govsa@ege.edu.tr, fgovsa@yahoo.com (F. Govsa).

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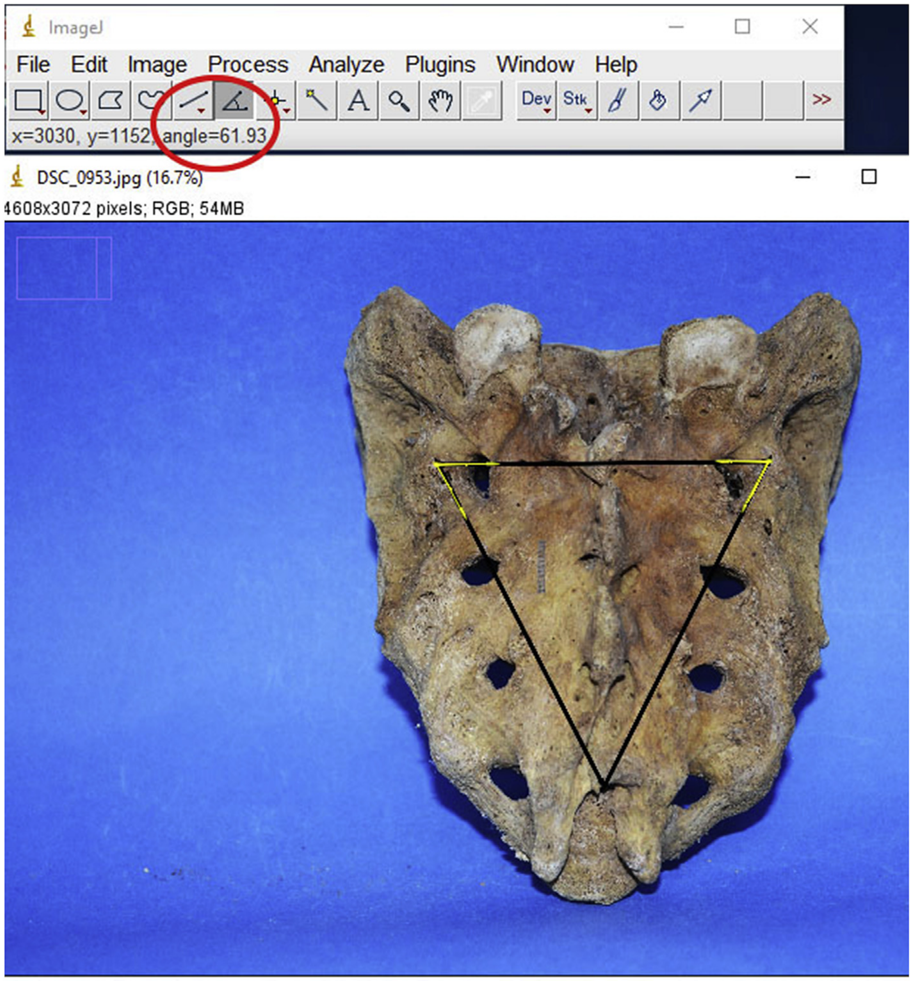

Fig. 1. Measurement of the angular parameters using Image J 1.47 version.

3. To demonstrate the osseous landmarks, orientation points, conduct detailed and standardized morphometric measurements and calculate safe areas for screw placement of the upper sacral segment.

2. Material and method

A total of 87 adult dry human sacral bones were used within this study. The bones of adult age and undetermined gender recently procured were subjected to the morphometric study (Figs. 1–5). The following linear and angular parameters were measured and described in Figs. 1–5 (Tables 1 and 2).

1. Linear parameters
   The height and the width of the S1 and S2 anterior and posterior sacral foramina.
   Interforaminal anterior and posterior transverse distances of the S1.
   Interforaminal anterior and posterior vertical distances of the S1.
   The S1 pedicle height.
   The S1 pedicle depth.
   Sacral pedicle and sacral wing borders of the S1.
   The height and the width of the S1 facet joint.
   The distance between two S1 facet joints.
   Superior surface anteroposterior and transverse diameters of the S1 body.
   The height of the S1 and S2 bodies.
   Sagittal and transverse diameters of the sacral canal at superior aperture.
   Interforaminal anterior and posterior transverse distances at S2.
   Interforaminal anterior and posterior vertical distances at S2.
   The S2 pedicle height.
   The S2 pedicle depth.
   Sacral pedicle and sacral wing borders of the S2.
   The height and the width of S2 facet joint.
   The distance between two S2 facet joints.
2. Angular parameters
   The S1 facet angle (x).
   The sacral pedicle anteromedial screw trajectory angle (y).
   The anterolaterally-oriented sacral wing screw trajectory angle (z).

The measurements were taken using digital calipers (a Vernier caliper sensitive to 0.1 mm) and calculated with photogrammetric methods using Image J program (Fig. 1).

All measurements are expressed as mean ± standard deviation. Pearson correlation test was performed to evaluate the relationship between the variables.

3. Results

3.1. Morphologic details

Irregularities that may have an effect on the osseous structure and safe corridor area were present on the bone structure of the upper sacral segment like dysmorphic sacrum, sacralization (41.9%) and lumbalization (12.9%) (Figs. 6–8). In dysmorphic specimens, the upper sacral

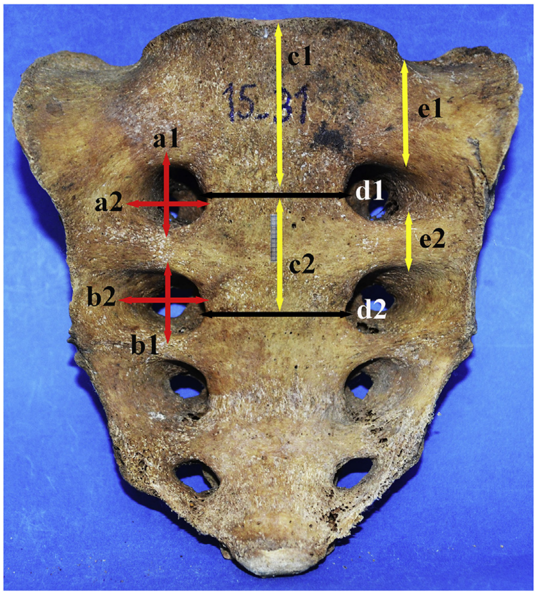

Fig. 2. Calculation of the linear parameters of the anterior face of upper sacrum: (**a1**) the height of the S1 anterior foramina; (**a2**) the width of the S1 anterior foramina; (**b1**) the height of the S2 anterior foramina; (**b2**) the width of the S2 anterior foramina; (**d1**) the transverse distance between the S1 anterior foramina; (**d2**) the transverse distance between the S2 anterior foramina; (**e1**) the distance between the S1 anterior foramen and the superior border of sacrum (anterior pedicle height); (**e2**) the distance between the inferior border of the S1 anterior foramen and the superior border of the S2 anterior foramen; (**c1**) the height of the S1 body; (**c2**) the height of the S2 body.

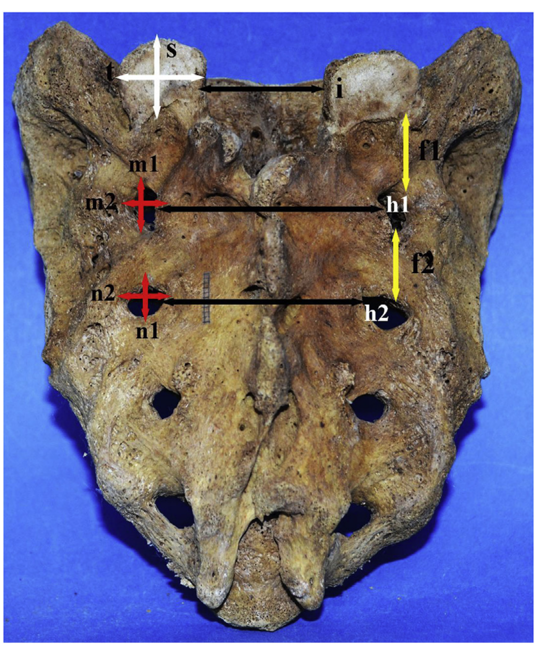

Fig. 3. Posterior view of upper sacral segment, linear parameters: (**m1**) the height of the S1 posterior foramina; (**m2**) the width of the S1 posterior foramina; (**n1**) the S2 posterior foramen height; (**n2**) the S2 posterior foramen width; (**h1**) the transverse distance between the S1 posterior foramina; (**h2**) the transverse distance between the S2 posterior foramina; (**f1**) the distance between the S1 posterior foramen and the superior border of the sacrum (posterior pedicle height); (**s**) the height of the S1 facet joint; (**o**) the width of the S1 facet joint; (**i**) the distance between two facet joints.

segment was significantly smaller and more oblique than normal. These sacrums were found an increased caudal to cranial and anterior

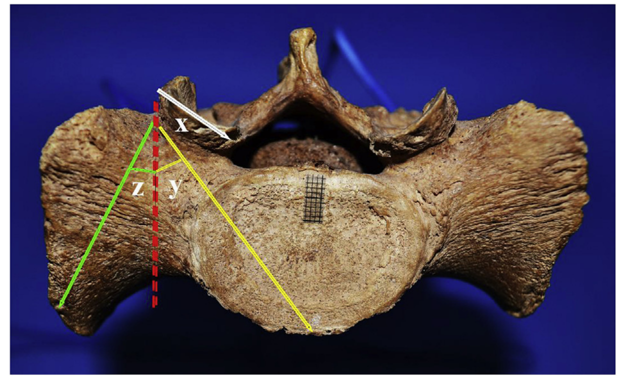

Fig. 4. Angular parameters (from the sagittal – dotted line): **(x)** the S1 facet angle; (**y**) the sacral pedicle anteromedial screw trajectory angle; (**z**) the anterolaterally-oriented sacral wing screw trajectory angle.

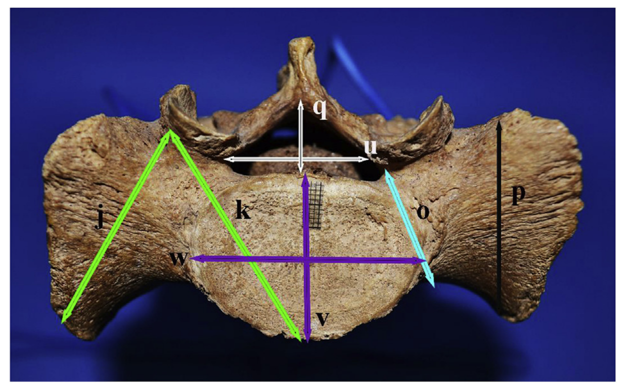

Fig. 5. Upper view of the sacrum. linear parameters, pedicle and wing: (**k**) the distance between the S1 pedicle entry point (inferolateral aspect of the S1 facet joint) and the anteromedial point of the S1 vertebra; (**j**) the distance between the S1 pedicle entry point and the anterolateral sacral wing; (**l**) the S1 pedicle depth; (**p**) the sacral wing depth; (**v**) the S1 vertebral body anteroposterior diameter; (**w**) the S1 vertebral body transverse diameter; (**q**) the sagittal diameter of the sacral canal at the superior aperture of the sacrum; (**u**) the transverse diameter of the sacral canal at the superior aperture of the sacrum.

posterior obliquity (Figs. 6–8).

3.2. Morphometric parameters

The results obtained from the linear and angular measurements were presented in Tables 1 and 2 In normal sacrums, the height and the width of the S1 anterior foramina were 14.2 ± 2 mm and 14.8 ± 2.5 mm, respectively. The height and the width of the S1 posterior foramina were 12.2 ± 1.3 mm and 8.7 ± 1.1 mm, respectively. The transverse distance between the S2 anterior foramina was 26.7 ± 3.3 mm. The distance between the S1 anterior foramen and the superior border of the sacrum (anterior pedicle height) was 15 ± 2.23 mm. The distance between the inferior border of the S1 anterior foramen and the superior border of the S2 anterior foramen was 10.3 ± 1.16 mm (Fig. 2). The distance between the S1 pedicle screw entry point and the most anteromedial point of the S1 vertebra was 52.8 ± 1.56 mm. The distance between the S1 pedicle screw entry point and the anterolateral sacral wing was 50.74 ± 1.48 mm (Fig. 5). The mean depths of the S1 pedicle and sacral wing were estimated at 25.8 ± 2.3 mm and 50.1 ± 1.7 mm, respectively.

3.3. Angular parameters

The sacral pedicle anteromedial screw trajectory angle was observed as 29.6 ± 0.9°. The anterolaterally oriented sacral wing screw

Table 1
The results of the linear measurements in millimeter (mm).

Measurements	Right (mm)	Left (mm)	Mean value
a1: The height of the first anterior sacral foramina	14.2 ± 2 (12–18)	13.74 ± 2.0	13.66 ± 2.11
a2: The width of the first anterior sacral foramina	13.78 ± 2.12	14.13 ± 2.1	13.95 ± 2.12
b1: The height of the first posterior sacral foramina	12.50 ± 3.31	12.44 ± 3.01	12.47 ± 3.16
b2: The width of the first posterior sacral foramina	8.14 ± 1.97	7.80 ± 1.82	7.97 ± 1.89
c1: The height of the second anterior sacral foramina	13.48 ± 2.26	13,72 ± 1,98	13,60 ± 2,12
c2: The width of the second anterior sacral foramina	13.97 ± 2.69	14.46 ± 2.27	14.22 ± 2.48
d1: The height of the second posterior sacral foramina	7.62 ± 1.54	7.61 ± 1.55	7.62 ± 1.54
d2: The width of the second posterior sacral foramina	8.04 ± 1.70	7.81 ± 1.78	7.92 ± 1.74
e1: The transverse distance between the first anterior sacral foramina	–	–	30.48 ± 2.78
e2: The transverse distance between the second anterior sacral foramina	–	–	28.31 ± 2.81
f1: The transverse distance between the first posterior sacral foramina	–	–	38.32 ± 3.63
f2: The transverse distance between the second posterior sacral foramina	–	–	31.62 ± 3.27
g1: The distance between the first anterior sacral foramen and the superior border of the sacrum (anterior pedicle height)	14.88 ± 2.38	14.75 ± 2.26	14.81 ± 2.32
g2: The distance between the inferior border of the first anterior sacral foramen and the superior border of the second anterior sacral foramen	10.79 ± 2.38	10.29 ± 2.11	10.54 ± 2.25
h: The distance between the first posterior sacral foramen and superior border of the sacrum (posterior pedicle height)	20.74 ± 2,50	21.23 ± 2.18	20.98 ± 2.34
i: The distance between the inferior border of the first posterior sacral foramen and the superior border of the second posterior sacral foramen	15.92 ± 2.05	15.92 ± 2.11	15.92 ± 2.08
j: The distance between the S1 pedicle entry point (inferolateral aspect of S1 facet joint) and the anteromedial point of the S1 vertebra	51.12 ± 4.83	51.26 ± 4.72	51.19 ± 4.77
k: The distance between the S1 pedicle entry point and the anterolateral sacral wing	50.13 ± 3.63	50.46 ± 3.51	50.30 ± 3.57
l: The S1 pedicle depth	24.69 ± 3.92	24.60 ± 3.75	24.65 ± 3.84
m: The sacral wing depth	53.88 ± 4.65	53.92 ± 4.12	53.90 ± 4.39
n: The height of the S1 facet joint	14.55 ± 1.82	14.69 ± 1.84	14.62 ± 1.83
o: The width of the S1 facet joint	16.44 ± 2.20	16.30 ± 2.08	16.37 ± 2.14
p: The distance between the S1 facet joints	–	–	25.68 ± 3.80
q: The S1 vertebral body anteroposterior diameters	–	–	31.42 ± 2.83
r: The S1 vertebral body transverse diameters	–	–	49.40 ± 5.89
s: The height of the S1 vertebral body	–	–	30.22 ± 2.35
t: The height of the S2 vertebral body	–	–	26.34 ± 6.09
u: The sagittal diamater of the sacral canal at the superior aperture of the sacrum	–	–	21.81 ± 3.66
v: The transverse diamater of the sacral canal at the superior aperture of the sacrum	–	–	31.31 ± 3.16

Table 2
The results of the angular (°) and linear (mm) measurements.

Measurements	Mean value
x: S1 facet angle	34.25 ± 0.95 (33–35)
y: Sacral pedicle anteromedial screw trajectory angle	29.6 ± 0.89 (29–31)
z: Anterolaterally oriented sacral wing screw trajectory angle	29.7 ± 2.06 (27–32)
Interforaminal posterior vertical distance (f2)	16.5 ± 2.3 (12–19)
The transverse distance between the first posterior sacral foramina (h1)	35.1 ± 1.5 (33–37)
The transverse distance between the second posterior sacral foramina (h2)	32.4 ± 1.7 (31–35)
Posterior pedicle height (f1)	20.4 ± 2.4 (17–28)

trajectory angle was 29.7 ± 2.1°. The heights of the S1 and S2 body were measured as 30 ± 4.6 mm and 24.9 ± 4.1 mm (Fig. 4). It was determined that in the comparison of the values of the S1 and S2 vertebras regarding the height, weight and the transverse distance, the figures of the S1 were higher. This showed us the fact that in cases where S1 was not appropriate to insert screws, values of the S2 could be used alternatively (Fig. 4).

3.4. Osseous corridors

In normal sacrums, iliosacral osseous corridors existed at the S1 and S2 vertebral levels. S1 corridor was in front of the sacral alar region, above S1 corridor and was suitable as L4 and L5 nerve route and internal iliac vessels. S2 corridor was present with the S1 foramen route above and S2 foramen with its nerve route below. Whereas the main corridor axis alignment was horizontal on the S2, two different osseous corridors can be addressed on the S1 vertebra, depending on the individual sacral shape as pattern as: (1) oblique iliosacral screw trajectory; and (2) transverse transsacral screw trajectory (Fig. 9).

In dysmorphic sacrum angulated and up-slopping sacral ala and obliquely atrophic transverse process were present in non circular – elliptical sacral neural foramina. It was also detected that the S2 corridors in contrast were perpendicular. The S2 segment safe in zone the cross-sectional area was clearer more than twice as large in dysmorphic sacral compared to normal one. In dysmorphic sacrums, the safe zone cross-sectional area was found over 30% smaller.

Statistical analysis of the S1 pedicle depth showed strong positive statistical correlation with the right and the left sacral wing depth as confirmed with Pearson's correlation (right 0.236 and left 0.869; correlation significant at 0.01 level two-tailed). Similarly, the sacral pedicle anteromedial screw trajectory line showed positive correlation with the S1 facet angle, the S1 pedicle depth and S1 pedicle height right and the left margins of the triangle (base 0.201, left 0.364, right 0.218; correlation significant at 0.01 level two-tailed).

4. Discussion

The upper sacral segment is a target point for sacral fixation procedures. Such instrumentation may carry the risks for sacral neurovascular injury resulting in morbidity, and even mortality. The sacral root or plexus injury may lead to painful deformity or progressive neurological dysfunction, and erectile or bowel and bladder dysfunction in 10%–34% of the patients.[1–9]

4.1. Shape of the upper sacrum

With wider use of screw fixations in different positions in the posterior pelvic ring (iliosacral or transsacral), several morphologic variations are described such as transitional vertebra, sacralization, lumbalization and dysmorphic sacrum.[3,12,16,30,31] However studies lack consensus regarding their definitions.

Accurate screw placement depends on experience, a thorough

Fig. 6. External aspect of the dysmorphic upper sacral segment samples **A-F**.

understanding of the injury and its radiographic and fluoroscopic appearance, and morphology of the upper sacral area. The drawback of transsacral screw fixation is the difficulty in placement owing to the individual variable three-dimensional anatomic shape of the upper sacrum (segmental kyphosis, dysmorphic sacrum, sacralization and lumbalization) (Figs. 6–8), with several neurovascular structures in close proximity to the osseous boundary.[24–26]

However, high incidence anatomical shape variations of the upper sacrum frequently leads to a complicated screw insertion or even prevention of screw placement in S1.[6–8,28–33] Such dysmorphic sacrum occur at a considerable rate of up to 35% in European and as high as 54% in Asian cohorts.[18,23,31,32] Radezki et al. indicate that screw fixation into the S2 segments could be considered for a two-level sacroiliac screw fixation in the "intermediate major" (12%) or "cephalad" (12%) sacral variants.[26] The latter variant is equivalent to the commonly used but with in inaccurate term "sacral dysplasia"; its anatomical limitations are the isthmus between the second and third sacral foramina and the iliac bone stock that is constrained by the posterior inferior iliac spine.

Sacral dysmorphic specimens can make transverse sacroiliac screw insertion into the first sacral segment impossible. Therefore, the S2 body has to be used optionally to achieve sacroiliac screw implantation. In cases of dysmorphic sacrum, or too-narrow transsacral S1 corridors, it may be possible to place only oblique sacroiliac screws, but alternative or additional iliosacral screw placement at the level of the S2 vertebra may be considered.[8,24,27,28,31,33] An additional sacroiliac screw placement into the S2 body might improve stability in elderly and in osteoporotic bone and could be performed regularly in the cases of

Fig. 7. Individual sacral shape as lumbalization pattern **arrow**.

Fig. 8. Changes geometry of the upper sacral segment with sacralization **arrow**.

dysmorphic sacra. A compensatory larger transsacral osseous S2 corridor in dysmorphic versus non dysmorphic sacra,[6,30,31] was confirmed in our study, as shown by a weak negative correlation of the S1 and S2 transsacral corridor diameters.

4.2. The S1 pedicle

The S1 pedicle height is greater than other pedicles. Previous studies report the pedicle height of the S1 anterior as 14.81 ± 2.32 mm and the posterior height as 20.98 ± 2.34 mm.[3] The mean height of the S1 vertebral body has been reported to be 21.2–28.9 mm for men and 20.2–27.7 mm for women.[29,31] In our study, the mean value was 30.22 ± 2.35 mm. There are two main screw trajectories for posterior sacral fixation, including the anteriomedial trajectory through the pedicle to the promontory and the anterolateral trajectory to the sacral wing.[13–17,34] Using an entry point just inferolateral to the S1 facet, this study determined the distance between the entry point of a screw in the dorsal surface of the sacrum and anteromedial cortex of the S1 promontory (k), as well as the distance between the same dorsal point and the anterolateral cortex of the sacral wing (j) (Fig. 3). The distance between the S1 pedicle entry point and anteromedial point of S1 vertebra is reported as 51.12 ± 4.83 mm on the right and 51.26 ± 4.72 mm on the left.[3] Arman et al. report the measured anterolateral distances of S1 as 50 mm.[3] In the study of Okutan et al., the S1 pedicle screw distance was reported as 52.3 ± 3.1 mm on the right and 52.3 ± 3.9 mm on the left for men, whereas the same length was 50.9 ± 3.9 mm on the right and 51.1 ± 3.7 mm on the left for women.[17] In the present study, the distance between the S1 pedicle entry point and sacral wing was 52.8 ± 1.56 mm on anteromedial border (k) and 50.74 ± 1.48 mm on the anterolateral border (j). The figures in our study as k 52.8 ± 1.86 and j 50.74 ± 1.5 mm are compatible with that of the previous study.

Previous studies have reported that the length of laterally-oriented sacral screws depends mainly on the degree of orientation. The angle of

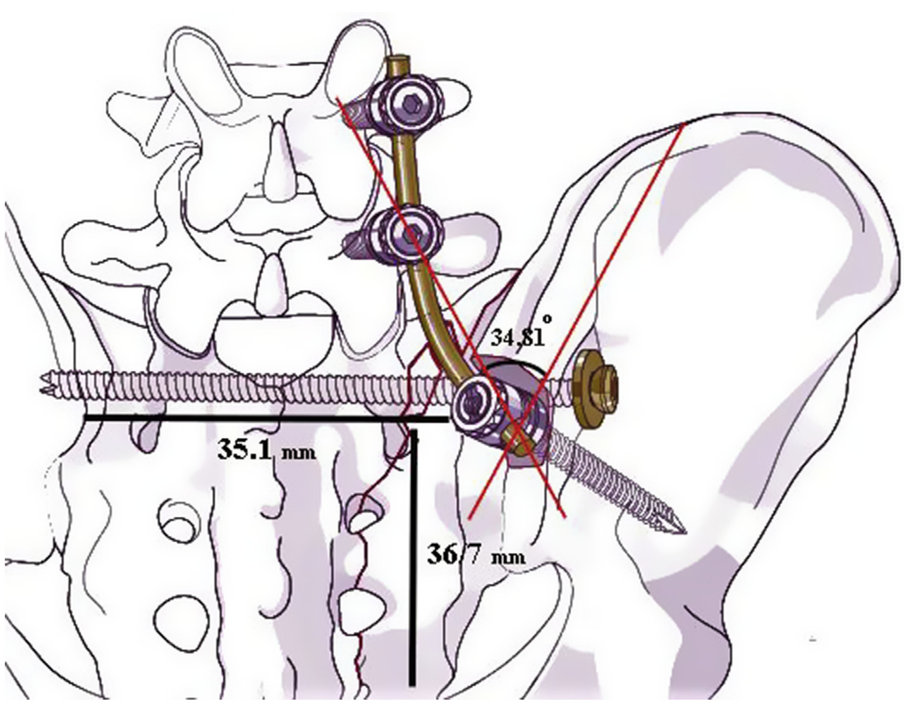

Fig. 9. Schematic illustration of the posterior view of sacroiliac junction presenting the location of the sacroiliac screw entry point. Depending on the individual sacral shape as pattern: oblique iliosacral screw trajectory; and transverse transsacral screw trajectory.

the pedicle is of importance as there is a risk of injury to neurovascular structures with poorly placed screws.[14,16,19,21,30] Additionally, the mean angles for appropriate screw placement is also measured for both anteromedial and anterolateral orientations. The screw angulation as 30° and the length of the screw as 38 mm (range 25–48 mm) were reported.[6,20] They also reported that 45° laterally-oriented screws to the sacral wing have a high potential for lumbosacral trunk impingement (55%) and the rate of sacroiliac joint injury is 10%. Preoperative CT scan verification is proposed to determine safe angles and to minimize the risks for screw placement.[15,22] The mean angle for appropriate placement of an anterolaterally-oriented sacral wing screw is found to be 32° on the right side and 29° on the left side.[34] In the present study, the mean angle for appropriate placement of the anteromedial transpedicle screw is measured as 35° and 31° on right and left sides, respectively.

4.2.1. The body of the S1

The anteroposterior and transverse diameters of the S1 body need to be taken into consideration during iliosacral screw procedures. Previous study, as in the reports of Arman, measured anteroposterior and transverse diameters of the S1 body as 31.42–45.4 mm and 30.5–49.4 mm, respectively.[3] As the relative dimensions of the S1 and S2 vertebral bodies are larger in men than women, the cross-sectional area of the S1 and S2 osseous corridors are significantly larger in men than women.[29,34] In their study, prior to performing an iliosacral screw, accurate analysis of the CT scan sacrum in each patient must be performed to determine if an osseous corridor is present. In the present study, anteroposterior and transverse diameters of the S1 body were 32.57 ± 1.16 mm and 49.9 ± 1.33 mm, respectively. Esenkaya et al. found the distances from the superior surface of the S1 body to the upper border of the first sacral foramen as 22.70 mm anteriorly and 23.07 mm posteriorly.[5] These distances reflect the vertical limits for screw placement without risk at S1.

4.2.2. The sacral wing

The sacral wing depth reflects the length needed for sacral wing screws. The sacral wing depth is reported as 45.8 ± 1.9 mm (43–50 mm).[3,15,19,20,33] The significant difference between these two studies can be explained by the differences in screw entry points of ethnic origins. In the present study the sacral wing depth was 50.1 ± 1.73 mm.

4.2.3. The sacral canal

The average sacral canal width is of 27.5 and 26.4 mm for men and women.[22,24] In the study of Arman, sagittal and transverse diameters of the sacral canal at the superior aperture of the sacrum are 21.81 ± 3.66 mm and 31.31 ± 3.16 mm, respectively.[3] In this study, sagittal and transverse diameters of the sacral canal at the superior aperture were 22.1 ± 3.36 mm and 27.5 ± 4.26 mm, respectively.

The iliosacral screw procedures are described the iliosacral screw passing posterior and cephalad to the sacroiliac joint and ending in the S1 body was described by Dubousset et al.[29] as a pelvic anchor for long spinal instrumentations. According to the technique described by Dubousset et al.,[29] the iliosacral screw has a variable entry point on the external cortex of the iliac bone. It passes posterior and cephalad to the sacroiliac joint and through a connector 10 mm embedded in a curetted hole at the base of the S1 superior articular process, runs caudal and parallel to the L5/S1 disc space and ends with a tip ideally located at the center of the S1 body.[29] In the original paper belonging to Yamada et al., starting point of superior anterior iliac spine is 1 mm inferior and 1 mm lateral to the S1 posterior foramen, and trajectory is 40–50° angulation relative to the horizontal line and 20–30° caudal from the straight line.[10]

Using the largest 10 mm diameter cut off, as reported by Gardner et al.[31] and Moed and Geer,[28] iliosacral osseous corridors at the S1 and S2 vertebrae would have been too narrow in 36% and 26% of pelves compared with 32% and 12% when using the 9 mm cut off. Measured cylindrical diameters in our study (S1, 13 ± 0.3 mm; S2, 12 ± 2 mm) are similar to those reported in previous studies[19] (S1: 14 ± 4 mm; S2 11 ± 3 mm). Minor differences in several studies may be attributed to heterogeneity of the groups based on sex or the measurement techniques as discussed in a recent study.[6]

The purpose of this study was to define the detailed anatomy of the upper sacrum and find the safest approach in sacral screw placement. Our study provides additional information regarding iliosacral osseous corridor-size distributions and proportions of S1 - S2 based on upper sacrum (Fig. 9). With respect to the anatomical conditions of the upper sacral segment, there have been no anatomical investigations to date regarding a realizable iliosacral screw placement into the S2 segment. An understanding of unique dimensions and configurations of the dysmorphic sacrum may allow S1 and/or S2 level iliosacral screw fixation. In the current study, the feasibility of a secure screw insertion through the upper sacral segment with dysmorphic sacrum and without sacral bony irregularities was determined. The feasibility of percutaneous fixation with iliosacral screws in S1 has been shown in several anatomical and clinical studies and case reports. In most studies, the figures were evaluated only in terms of the S1 measurements screws devoid of S1 and S2 together with the upper sacral segment.[5,15,19,33] Although there are case studies presented as articles, only a few of them target the feasibility of the S2 for screwing, except S1.[22,24] Our study focused not only the screwing process in the S1 affecting the upper sacral area of the patients with bone deformities, and with less bone density but also the application of cases with safe corridors of the S2 (Figs. 6-8). The reason is that in many cases with some pelvic structures where S1 is short or narrow angled and unsuitable for screwing due to sacralization and lumbalisation, S2 may serve as an alternative route for the procedure. This has now become a valuable procedure after it had previously been largely avoided. The measurements of this citation are included in the study. It also shows that there is no significant difference in the distances for anteromedially - (into the promontorium) and anterolaterally - (into the sacral wing) directed screw paths (Fig. 9). The main factors affecting the length and angle of an S1 anteromedially - or anterolaterally - placed screw is the location of the screw entry point (Fig. 5).

The most commonly used landmarks of the S1 pedicle depth, the sacral wing depth, anteromedial and anterolateral screw trajectory angle are indicated in the procedure of screwing. The distance between the most lateral borders of the foramens of the S1 vertebra was approximately equal to the actual length of screw trajectory when the screw is to be directed toward the sacral promontory. Interforaminal distance of S1 is also another important landmark (Tables 1 and 2).

This study demonstrates the presence of S1 osseous tunnels allowing a passage of an 8 mm trans iliosacral in the majority of subjects. Where this is not possible, it is most likely due to sacral dysmorphic. The incidence of dysmorphic or transitional vertebra is an unignorable fact. Shape of the upper sacrum is also essential. Common problems in the detection of S1 as a landmark include being dysmorphic and shorter than 2 mm. Failure to observe this may lead to the compromise of the neurovascular structures anteriorly or penetration of the sacral canal posteriorly. When using the S1 pedicle depth as a navigational way point, operating beyond a distance of less than 10 mm with 6% is associated with an increased risk of applying screw to the S1, the contents of which should be scopied. In 9% of the cases, the osseous irregularities of the S1 were detected. This means that in 15% of the cases inserting the screws will be difficult.

These main conclusions may be drawn from our study. These are:

- Comprehensive demonstrates each site of injury or degenerative, including its displacement and signs of instability, as well as baseline anatomic features, including bone quality and morphology.
- Patient's individual upper sacral osseous anatomy (normal or dysmorphic). To achieve the strongest biomechanical stability and to

avoid injury to anterior sacral structures, it is crucial to determine the optimum screw length for each individual surgery in S1 screw insertion. Dysmorphic sacrums were detected through an adequate S2 segment, rather than the dysmorphic first segment. S1 foramens were not round, as the lower ones. Upper left pathway was slightly cranial to the second sacral foramina.

- Patient's specific unstable sacral configuration (fracture or degenerative conditions). The measurement of the distance between the most lateral borders of interforaminal distance of S1 is approximately equal to the actual anteromedial screw length.
- High quality pelvic CTs including 3D images if available are crucial for planning reduction maneuvers and safe, effective paths for iliosacral placement. Interforaminal distance of the S1 could be used for surgical planning purposes to determine the appropriate length for the medially directed S1 screws.
- Preoperative planning of optimal iliosacral approach type, location and screw length selection of screw channels (S1 and S2). The actual anteromedial S1 screw length is the distance between the inferolateral aspect of the superior facet of the S1 and the promontorium.
- If upper sacral segment (oblique) screws are also desired, they should be inserted before the second segment transsacral screw, since the latter ones prevents the visualization of the upper segment anterior alar indentations, which are anterior limit to the upper segment screw placement.

5. Conclusions

Prior to sacral screw placement, using large range of distances and anatomical landmarks as well as detecting the presence of bony irregularities that belong to dysmorphic sacrum should be taken into consideration. To avoid injury to the vascular structures anteriorly and nerve roots medially, the depth and the angle of screw trajectory is important for the entrance off pedicular screw placement to the S1. Accurate screw placement depends on experience, a thorough understanding of the injury and its radiological, fluoroscopic images and 3D personalized models of iliosacral screwing.

Conflicts of interest

No financial conflict of interest exists with any commercial entity whose products are described, reviewed, evaluated or compared in the manuscript. None of the authors has a financial interest in any of the product, devices or drugs mentioned in this article.

Author contributions

Study design KA, MO: Data assembly OS: Data analysis MAO, OD: Final approval of manuscript FG, KA.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jor.2019.04.010.

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