Turkish Journal of Medical Sciences

Volume 47 | Number 3 Article 36

1-1-2017

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TÜBİTAK

Turkish Journal of Medical Sciences

http://journals.tubitak.gov.tr/medical/

Research Article

Turk J Med Sci
(2017) 47: 954-959
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doi:10.3906/sag-1505-84

Morphometric study of the true S1 and S2 of the normal and dysmorphic sacralized sacra

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Received: 20.05.2015 • **Accepted/Published Online:** 26.12.2015 • **Final Version:** 12.06.2017

Background/aim: This study aimed to generate data for the S1 and S2 alar pedicle and body and the alar orientations for both dysmorphic and normal sacra.

Materials and methods: The study comprised two groups: Group N consisted of 53 normal sacra and Group D included 10 dysmorphic sacra. Various features such as alar pedicle circumference; anterior, middle, and posterior axis of the sacral ala; sacral body height and width; and sagittal thickness were measured.

Results: In group N, the median anterior axis of the alae was observed to be 30° on the right and 25° on the left, the median midline axis was found to be 20° on the right and 15° on the left, and the median posterior alar axis was –15° on the right and –20° on the left. The true S1 and S2 alar pedicle circumferences were observed to be significantly smaller in group D, which demonstrated a shorter S1 alar pedicle mean circumference, significantly narrower S1 body mean width, and considerably tapered sagittal thickness.

Conclusion: Our analysis indicated that dysmorphic sacra have a lower sagittal thickness and width of bodies and smaller alar pedicles, which explains the difficulties in their percutaneous fixation.

Key words: Dysmorphic sacrum, sacralization, iliosacral fixation, alar pedicle

1. Introduction

The sacrum exhibits a complex anatomy with a high rate of variations. In view of this, determination of anatomical knowledge of the sacrum, with particular emphasis on iliosacral screw fixation, has become essential to surgeons who are working in the field of pelvic trauma (1). Considering the fact that sacral dysmorphism occurs in 30%–40% adults, it is not an uncommon condition (2). The most common cause of dysmorphism is the fusion of L5 to the sacrum with a narrow osseous pathway called sacralization, which constitutes at least half of the cases. In this scenario, the sacrum is often elevated from the iliac wing, displays conspicuous mammillary processes, and has a sharper alar slope, as well. The dysmorphic upper sacral anatomy provides consistent yet atypical alar pedicle (so-called safe zone or osseous pathway) sizes and angles that mandate very important technical and radiographic alterations when S1 and S2 sacral segment iliosacral screws are to be placed (3–8). Considering the potential risks of percutaneous iliosacral fixation, which include neurovascular damage (8–11), some of the researchers working in the field have attempted to quantify the upper sacral morphology of normal and dysmorphic sacra by CT-based studies (8,12,13). Gardner et al. (12) reported that the orientations and cross-sections of the safe bone pathway are quite different between the normal and dysmorphic sacra, and they recommended S2 to be a primary zone for the fixation of the dysmorphic sacra. Similarly, in another CT imaging study, Conflitti et al. (8) reported that the second upper sacral segment had a larger and longer safe bone pathway when compared to the first one, which was also anatomically competent for screw fixation.

Therefore, as an attempt to further analyze sacral anatomy, the present study was carried out to generate data on dry bone for S0 (sacralized L5 segment, which

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is often referred to as S1 of the dysmorphic sacra in the literature), true S1 and S2 body sizes and alar pedicles, alar orientations, and sacral posterolateral groove depth for both dysmorphic and normal sacra. Moreover, comparison of the two sides of the sacrum was also intended for the identification of any asymmetry.

2. Materials and methods

This study analyzed dry bone specimens, which consisted of 53 normal sacra (Group N) and 10 dysmorphic sacralized sacra (Group D) that were procured from the Hacettepe University Faculty of Medicine's Department of Anatomy, Ankara, Turkey. Dysmorphic sacralized sacra were distinguished by having at least two of the following: 5 pairs of anterior foramens, an apparent disk space between the first two segments, an acute alar slope, or hypertrophic mamillary processes (Figures 1A and 1B). The length measurements were done by a digital compass (calipers), which had an accuracy of 0.01 mm, while the angular measurements were performed with a goniometer with 1° of accuracy. All symmetric structures were measured bilaterally. All of the measurements were done blindly by two anatomists (AF, NÇ) by determining the reference points for each measurement. The intraobserver reliabilities of the measurements of the two blind researchers for 10 N and 10 D sacra were estimated statistically by a research assistant of the Department of Biostatistics of Hacettepe University.

The width and height of S1 and S2 sacral foramina (from both the anterior and the posterior aspects) were measured via a horizontal and a vertical line that were vertical to each other in the center of the foramina and passing through the outermost edges of the foramina (Figure 2). The next set of measurements was made on the width-height-sagittal thickness of S1 and S2 sacral vertebral bodies. The widths of the S1 and S2 bodies were measured as the far-most points of the superior articular surface on the horizontal plane, the heights of the S1 and S2 bodies were measured via the midsagittal line between the uppermost and lowermost edges, and the sagittal thicknesses were measured by the midsagittal line on the articular surface passing through the outermost anterior and posterior points. Circumferences of alar pedicles were measured by wrapping a fiber around the isthmus of the pedicles (Figure 1A). The isthmus of the pedicles was determined by the narrowest part between the body and the sacral ala, and all measurements were made at this level bilaterally (Figure 1A). The depth of the alar recess was measured after a ruler was anteriorly bridged to the ala mimicking a line from the most anterior corner of the ala to the promontorium, and alar recess depth was drawn perpendicular to the white line to the deepest point of the ala (Figure 1).

An inlet view was mimicked for S1 for Group N and the true S1 for Group D for the measurement of anterior, middle, and posterior orientations of alar pedicles. It was the caudal projection of the sacrum and was assumed as the best assessment of the sacral spinal canal and superior view of S1. The measurements of the orientations of the alar pedicles were made by the simulation of the inlet position with a parallel sight to the anterior upper sacral body wall (14). The angles between anterior, middle, and posterior longitudinal axes of the alar pedicles and the coronal plane were also measured (Figures 1A and 1B). Here the anterior longitudinal axis of the alar pedicle was determined by a line between the most anterior tip of the sacral ala and the

(A) (B)

Figure 1. Normal (A) and dysmorphic sacralized (B) sacra. Inlet view is mimicked for S1 for Group N and the true S1 for Group D for the measurement of anterior, middle, and posterior orientations of alar pedicles (black dotted arrows). A white line is drawn from the most anterior corner of the ala to the promontorium; alar recess depth is drawn perpendicular to the white line to the deepest point of the ala (shown by dotted white line). Pedicle circumference is measured by wrapping a fiber around the isthmus of the pedicles.

center of the sacral body on the coronal plane, the middle longitudinal axis was determined by a line between the middle point of the isthmus and the center of the sacral body on the coronal plane, and the posterior longitudinal axis of the alar pedicle was determined by a line between the most posterior tip of the sacral ala and the center of the sacral body on the coronal plane.

On the other hand, the angle between the horizontal axis of the alar pedicle and the horizontal plane was estimated by a simulation of the outlet position with a perpendicular sight to the anterior upper sacral body wall. Outlet positioning of the sacrum provides a true anteroposterior view of the sacrum (Figure 2). In outlet positioning, the foramina and vertebral bodies were clearly observed for morphological evaluation. For the horizontal axis of the alar pedicle, we determined a line between the tip of the uppermost anterior point of the sacral body and the most anterior tip of the sacral ala. The vertical and horizontal diameters of S1 and S2 foramina were also measured in this position via a horizontal and a vertical line that were vertical to each other in the center of the foramina and passing through the outermost edges of the foramina (Figure 2). The depth of the posterolateral superior and inferior grooves that accommodate the sacroiliac ligament was also measured with a digital compass. For each groove, we positioned a horizontal plane by using a ruler sitting on the edges of the groove and measured the distance between the deepest part of the groove with the horizontal plane (Figure 3).

2.1. Statistical analysis

The Kolmogorov–Smirnov test was applied to determine the normality of the distribution. The data were statistically analyzed with the Mann–Whitney U, the Wilcoxon signed rank test, and marginal homogeneity tests depending upon the type of analysis. The intraobserver reliabilities of the measurements were estimated with the Spearman correlation test.

3. Results

3.1. S1 and S2: height, width, and sagittal thickness

The mean height of the S1 body was similar in the two groups. The values for Group N and Group D were 29.8 ± 2.3 mm and 29.5 ± 3.5 mm, respectively ($P = 0.45$). The mean width for the body ($P < 0.001$) and the sagittal thickness ($P < 0.001$) for S1 were significantly lower in Group D than Group N (Table 1).

In contrast to Group N, the body mean height, width, and sagittal thickness of S2 were found to be considerably smaller in Group D, at $P = 0.041$, $P = 0.03$, and $P = 0.001$, respectively.

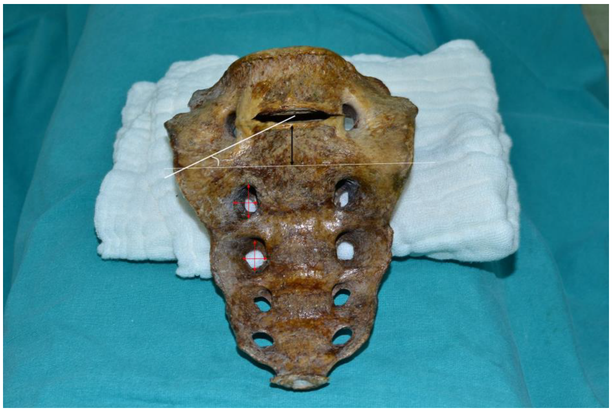

Figure 2. Outlet view is mimicked for measurement of the true S1 (black arrow) and S2 height, cephalad axis (angle between white lines), and anterior foramen diameters (red arrows).

Figure 3. The superior (white arrows) and inferior (black arrows) posterolateral grooves of a dysmorphic sacralized sacrum.

Table 1. Comparison of the size of S1 and S2 bodies in normal and dysmorphic sacra.

	S1 body (mm)			S2 body (mm)		
	N	D	P-value	N	D	P-value
Height	29.8 ± 2.3	29.5 ± 3.5	0.450	24.5 ± 3.1	23.0 ± 1.7	0.041
Width	46.0 ± 5.6	36.2 ± 5.6	<0.001	30.5 ± 2.6	28.4 ± 2.3	0.030
Sagittal thickness	29.6 ± 4.4	16.8 ± 4.6	<0.001	17.7 ± 3.3	12.5 ± 3.2	0.001

3.2. The circumference of alar pedicles

The circumferences of S1 alar pedicles in Group D (80.43 ± 11.06 mm on the right and 81.58 ± 9.78 mm on the left) were shorter than those in Group N (92.06 ± 7.71 mm on the right and 92.44 ± 9.45 mm on the left) (P = 0.006 on the right and P = 0.002 on the left). Likewise, the circumferences of the S2 alar pedicle in Group D (58.47 ± 4.53 mm on the right and 57.47 ± 4.92 mm on the left) were significantly shorter than those in Group N (70.43 ± 8.95 mm on the right and 69.24 ± 6.65 mm on the left) (P < 0.001 on the right and P < 0.001 on the left) (Table 2).

The circumferences of S0 alar pedicles were 85.62 ± 11.13 mm on the right and 84.03 ± 8.59 mm on the left side in Group D.

3.3. S1 and S2 foramina

For the right side, both the ventral and dorsal S1 foramina of Group D were smaller than those for Group N (P = 0.045 and 0.046, respectively). No difference in the S2 foramina sizes for either ventral (P = 0.28) or dorsal (0.28) measurements was observed.

For the left side, there was no significant difference between the two groups for S1 or S2 ventral and dorsal alar pedicles (P > 0.05).

3.4. The depth of alar recesses

The left sides were found to have considerably deeper recesses in Group D than Group N (12.15 ± 2.93 mm vs. 8.89 ± 1.39 mm, P = 0.002); however, no significant difference between the right side recesses of Group D and Group N (10.83 ± 2.66 mm vs. 9.39 ± 1.67 mm, P = 0.135) was observed. There was no difference between the two sides (right and left) within each group (P > 0.05).

3.5. The groove depth of the origin of the posterior sacroiliac ligament

Superior grooves were significantly deeper in group D than group N (10.69 ± 3.76 mm vs. 4.30 ± 3.52 mm, P = 0.001 on the right side; 8.57 ± 2.88 mm vs. 4.56 ± 3.33 mm, P = 0.006 on the left side). The right side inferior groove was measured to be 3.14 ± 3.47 mm in Group N and 5.09 ± 7.31 mm in Group D (P = 0.8). The left side inferior groove was estimated as 3.36 ± 3.77 mm in Group N and 2.28 ± 2.83 mm in Group D (P = 0.7).

3.6. The axis of anterior line, midline, and posterior line in inlet position

In the nondysmorphic sacra, the right ala had a significant anterior torsion in contrast to the left ala. In Group N, the median anterior axis of the alae was measured to be 30° on the right and 25° on the left side (P < 0.001). The median midline axis was found to be 20° on the right and 15° on the left side (P < 0.001), while the posterior alar axis was estimated as −15° on the right and −20° on the left (P < 0.001) (Table 3).

In the dysmorphic group, the right sacral ala had a minor anterior torsion (2.5° in the anterior and midline axis) compared to the left ala in Group D, which was insignificant for the anterior line (P = 0.47), midline (P = 0.12), and posterior line (P = 0.89).

Table 2. Comparison of the S1 and S2 alar pedicle circumferences between the normal and dysmorphic sacra.

	Right (mm)			Left (mm)		
	N	D	P-value	N	D	P-value
S0 alar pedicle	-	85.62 ± 11.13	-	-	84.03 ± 9.78	
S1 alar pedicle	92.06 ± 7.71	80.43 ± 11.06	0.006	92.44 ± 9.45	81.58 ± 9.78	0.002
S2 alar pedicle	70.43 ± 8.95	58.47 ± 4.53	<0.001	69.24 ± 6.65	57.47 ± 4.92	<0.001

Table 3. Comparison: a) cephalad axis of the superior borderline of the alae by mimicking the outlet view, b) anterior and posterior border lines and midline axis of the alae with coronal plane by mimicking the inlet view.

	N			D		
	Right	Left	P-value	Right	Left	P-value
Cephalad axis	30°	25°	<0.001	27.5°	25°	0.16
Anterior line	30°	25°	<0.001	32.5°	30°	0.47
Midline	20°	15°	<0.001	20°	20°	0.12
Posterior line	−15°	−20°	<0.001	−15°	−15°	0.89

3.7. The axis of the S1 alar pedicle in outlet position

In Group N, the median cephalad axis of the S1 alar pedicle was measured to be 30° on the right and 25° on the left, whereas it was estimated as 27.5° on the right and 25° on the left for Group D specimens. Furthermore, the difference between the two sides was significant in Group N ($P < 0.001$) (Table 3); however, the same was found to be insignificant for Group D ($P = 0.16$). Thus, the comparison between Groups N and D was not significant ($P = 0.95$ on the right and $P = 0.29$ on the left).

4. Discussion

Sacral dysmorphism is often a part of, but not limited to, the sacralization of the L5 vertebra, which is placed over the true S1. Dysmorphism can also be seen in the lumbarization of the S1 vertebra. Other morphological definitions of dysmorphism include: 1) a more cephalic position of the first sacral segment (which is consistent with the sacralization of L5) than the iliac crest, 2) hypertrophic mamillary processes, 3) identifiable disk space between the first two segments, 4) an acute alar slope, 5) large and misshapen S1 anterior foramina, and 6) deep anterior wall recesses (6,15,16). In clinical practice, a dysmorphic sacrum is important as it is much more challenging for an iliosacral screw fixation, which often necessitates some new techniques (17,18). Alar pedicles constitute the safe zone, as they are the only bony bridges from the sacral ala to sacral bodies. Pedicles are surrounded by sacral foramens and roots just above and below the sacral canal, which lays behind with the pelvic space on the front (15). The dangers of iliosacral screw placement include neurological palsy due to root or sacral canal engagement and potential risks of common iliac vein injury (1,4,9,13–17).

The most important finding of the present work was the identification of the small size of the true S1 and S2 bodies and alar pedicles of the dysmorphic sacra. This finding indicates a very narrow anteroposterior angular tolerance in orientation during iliosacral fixation of such a dysmorphic sacrum as the sagittal thickness of the body is undersized in dysmorphic sacra. Particularly on the left side, the anterior alar recess was found to be deeper in the dysmorphic sacra and this finding draws further attention. To our knowledge, this is the first study that compared miscellaneous features of dysmorphic and normal sacra with dry bone rather than CT imaging. Thus, this study outlines the occurrence of possible imaging errors. Another important result was that the alar pedicle angles of S1 in Group N and the true S1 in Group D were almost the same. Thus, the true S1 segment should be fixed during iliosacral fixation, omitting the sacralized L5. However, previous literature compared the sacralized L5 of dysmorphic sacra, which has a more vertical orientation, with the S1 of nondysmorphic sacra.

Our results indicate that the sacrum exhibited significant asymmetry due to orientations of the alar axis. In contrast to the left side, the right side of the normal sacra had 5° of anterior torsion. This observation might be important, as the starting point at the left side might be more posterior and the direction might be more ventral, by about 5°, when compared to the other side. This can be inferred from the theoretical relevance of the dominant side of the lower extremity that transfers the load from the body to the legs.

According to our findings, sacralized dysmorphic sacra had smaller alar pedicles and thinner true S1 and S2 vertebral bodies. However, the S0 alar pedicles were comparable with S1, which may permit a screw to enter sufficiently and reliably into the S0 body. Conflitti et al. (8) previously reported the S2 alar pedicles (should be the true S1) to be larger than S1 (should be the true S0 or sacralized L5) alar pedicles. Gardner et al. (12) reported that the second segment's safe zone cross-sectional area was more than twice as large in dysmorphic sacra than in normal sacra. However, as per our results, the pedicle circumference of S0 was slightly greater than that of the true S1.

The noncircular and misshapen anterior and abnormally large S1 anterior foramen have also been suggested as criteria for the discrimination of a dysmorphic sacrum (6,16). Likewise, in the present study, only the first upper foramens of Group D were found to be significantly smaller in size, as compared to Group N, while there was no difference between the groups for the lower foramens. Thus, our findings also support the previous observation of Conflitti et al. that dysmorphic sacra have deeper posterolateral grooves (6).

The limitation of the current work is the unbalanced specimen size for the two study groups, which can be attributed to the natural incidence ratio of the nondysmorphic and dysmorphic sacra. Although dysmorphism has been clinically described by radiographical findings, it was quite easy to find the sacralized dysmorphic sacra, which had five pairs of sacral foramens, an alar slope of more than 30°, and prominent mamillary processes.

In conclusion, dysmorphic sacra have a lower sagittal thickness and width of sacral bodies and smaller true S1 and S2 alar pedicles when compared to normal sacra. On the other hand, there were no significant angular differences between normal and dysmorphic true S1s. Thus, the basic difficulties during percutaneous fixation of the true S1 segment of dysmorphic sacra are narrow safe pathways (alar pedicles) and small targets (true S1 and S2 bodies). Thus, there is a very narrow anteroposterior angular tolerance in orientation during iliosacral fixation of a sacralized dysmorphic sacrum. Smaller diameters (6.5 mm rather than 7.3 mm) and single screws can be recommended in such patients.

References

1. Sagi HC, Lindvall EM. Inadvertent intraforaminal iliosacral screw placement despite apparent appropriate positioning on intraoperative fluoroscopy. J Orthop Trauma 2005; 19: 130-133.
2. Chip MLC, Simonian PT, Agnew SG, Mann FA. Radiographic recognition of the sacral alar slope for optimal placement of iliosacral screws: a cadaveric and clinical study. J Orthop Trauma 1996; 10: 171-177.
3. Carlson DA, Scheid DK, Maar DC, Baele JR, Kaehr DM. Safe placement of S1 and S2 iliosacral screws: the "vestibule" concept. J Orthop Trauma 2000; 14: 264-269.
4. Day AC, Stott PM, Boden RA. The accuracy of computer assisted percutaneous iliosacral screw placement. Clin Orthop Relat Res 2007; 463: 179-186.
5. Moed BR, Geer BL. S2 iliosacral screw fixation for disruptions of the posterior pelvic ring: a report of 49 cases. J Orthop Trauma 2006; 20: 378-383.
6. Wolinsky P, Lee M. The effect of C-arm malrotation on iliosacral screw placement. J Orthop Trauma 2007; 21: 427-434.
7. Ziran BH, Wasan AD, Marks DM, Olson SA, Chapman MW. Fluoroscopic imaging guides of the posterior pelvis pertaining to iliosacral screw placement. J Trauma 2007; 62: 347-356.
8. Conflitti JM, Graves ML, Chip Routt ML Jr. Radiographic quantification and analysis of dysmorphic upper sacral osseous anatomy and associated iliosacral screw insertions. J Orthop Trauma 2010; 24: 630-636.
9. Routt ML, Simonian PT, Mills WJ. Iliosacral screw fixation: early complications of the percutaneous technique. J Orthop Trauma 1997; 11: 584 -589.
10. Sagi HC. Pelvic ring fractures. In: Bucholz RW, Heckman JD, Court-Brown CM, Tornetta P, editors. Rockwood and Green's Fractures in Adults. Philadelphia, PA, USA: Lippincott Williams & Wilkins; 2010. pp. 1415-1462.
11. Weil YA, Nousiainen MT, Helfet DL. Removal of an iliosacral screw entrapping the L5 nerve root after failed posterior pelvic ring fixation: a case report. J Orthop Trauma 2007; 21: 414-417.
12. Gardner MJ, Morshed S, Nork SE, Ricci WM, Chip Routt ML Jr. Quantification of the upper and second sacral segment safe zones in normal and dysmorphic sacra. J Orthop Trauma 2010; 24: 622-629.
13. Mendel T, Noser H, Kuervers J, Goehre F, Hofmann GO, Radetzki F. The influence of sacral morphology on the existence of secure S1 and S2 transverse bone corridors for iliosacroiliac screw fixation. Injury 2013; 44: 1773-1779.
14. Ozmeric A, Yucens M, Gultaç E, Açar HI, Aydogan NH, Gül D, Alemdaroglu KB. Are two different projections of the inlet view necessary for the percutaneous placement of iliosacral screws? Bone Joint J 2015; 97: 705-710.
15. Mendel T, Noser H, Wohlrab D, Stock K, Radetzki F. The lateral sacral triangle – a decision support for secure transverse sacroiliac screw fixation. Injury 2011; 42: 1164-1170.
16. Tonetti J, van Overschelde J, Sadok B, Vouaillat H, Eid A. Percutaneous ilio-sacral screw insertion. Fluoroscopic techniques. Orthop Traumat Surg Res 2013; 99: 965-972.
17. Alemdaroğlu KB, Yücens M, Kara T, Gül D, Aydoğan NH. Pedicle axis view combined by sacral mapping can decrease fluoroscopic shot count in percutaneous iliosacral screw placement. Injury 2014; 45: 1921-1927.
18. Mendel T, Wohlrab D, Radetzki F, Hofmann GO. The smart screw: a fancy skill for sacroiliac screw insertion. J Trauma Acute Care Surg 2012; 72: 1089-1092.