Morphometric characteristics of the sacrum in a Mexican population: importance in lumbosacral fusion and fixation procedures

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Abstract

Introduction: The morphology and characteristics of the sacral vertebrae and its components determine the size and orientation of pedicular implants at the time of implantation. The objective of the study was to determine the morphometric characteristics of the sacrum in a Mexican population.

Methods: We carried out an observational, cross-sectional, descriptive and noncomparative study that analyzed 50 sacrums from the Department of Human Anatomy, Faculty of Medicine of the Universidad Autónoma de Nuevo León, Mexico.

Results. Characteristics of morphometric parameters were measured (39 linear and five angular). In S1 the average distance of the anteriomedial screw trajectory was 50.08 mm ± 3.72 with an average angle of 34.30º ± 4.1 from the screw entry point.

Conclusions: Study results are important for correct screw placement and position in lumbosacral instrumentation as well as for other procedures that involve the sacral region as a surgical and diagnostic target.

Key words: sacrum, pedicle, morphometry, transpedicular screws.

Introduction

The sacrum and its components represent the surgical objective of some clinical and surgical procedures such as epidural caudal block for the treatment of chronic pain caused by bone metastases in cancer patients, posterior decompression of the spinal canal, instrumented lumbosacral fusion and fixation.[1,2] The latter has been used for years for the treatment of spinal segmental instability caused by lumbar spinal canal stenosis, rupture of the sacroiliac joint, lumbar scoliosis, degenerative diseases of the spine, spondylolisthesis, and for conditions related to vascular, infectious, metastatic, congenital and traumatic origin.[3-6]

Morphometric characteristics of the sacral vertebrae determine the size and length of the pedicle screws as well as the ideal direction and angulation of the screw at the time of its introduction.[7] It is important to know these characteristics in order to avoid injury to the pedicle cortex, nerve roots, facet joints or adjacent vascular structures due to improper positioning or orientation of the screws.[5] The point of entry of the sacral screws corresponds to the inferolateral surface of the articular facet of the first sacral vertebra (S1) and these can be inserted in the sacral wings (anterolateral approach) or in the sacral promontory (anteromedial approach).[6] The latter approach is the one most used at present.[8] The objective of the study was to determine the linear and angular characteristics of the sacrum in a Mexican population.

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Methods

We carried out an observational, cross-sectional, descriptive and comparative study analyzing 50 dried sacrums obtained from the Department of Human Anatomy, Faculty of Medicine, University of Nuevo Leon. Those that were structurally damaged or with disease or obvious abnormality were eliminated. Linear and angular measurements were

carried out. In each piece studied, data were collected using a digital vernier with an accuracy of 0.01 mm and a goniometer with an accuracy of 0.1°. All measurements are reported in millimeters and degrees.

Measurement parameters were divided into five categories: 1) anterior and posterior sacral foramina, 2) S1 vertebral pedicle and intermediate crests, 3) vertebral body and general parameters of the sacrum, 4) superior articular facet of S1 and sacral canal, and 5) approaches of the S1 pedicle.

Category 1—Anterior and posterior sacral foramina (parameters A1-H3)

In this category three linear measurement parameters are considered: the length and breadth of the first three pairs of anterior sacral foramina (parameters A, A1, C, C1, E, E1) and posterior (parameters B, B1, D, D1, F, F1), horizontal distance between the left and right sacral foramen of the first three pairs of anterior sacral foramina (parameters G1, G2, G3) and posterior (parameters H1, H2, H3). For purposes of this study, the length of a sacral foramen was considered as the distance that exists between its superior and inferior margin; the width as the distance between the medial and lateral border of the foramen and horizontal distance between two sacral foramina as the distance that exists between both medial borders of the corresponding pair of sacral foramina (Figures 1 and 2).

Category 2—S1 vertebral pedicle and intermediate crests (parameters I-L2)

The following measurements were carried out for this category: length (parameter I) and height of the S1 pedicle for its anterior face (parameter J1) and posterior face (parameter J2) as well as the height of the intermediate crests of S2 and S3 for its anterior face (parameters K1, L1) and posterior face (parameters K2, L2) (Figures 1-3).

The length is defined as the distance between the posterior border and the anterior border of the S1 pedicle. The height was taken as the vertical distance between the superior border of the first anterior or posterior sacral foramen and the superior surface of the body of the S1 vertebra.

Category 3—Vertebral bodies and general parameters of the sacrum (parameters M-O3 and Y-Z)

Anteroposterior and transverse diameters of S1 were included in this category (parameters M, N), anterior height of the body of the first, second and third vertebra (parameters O1, O2, O3) as well as length (parameter Y) and width
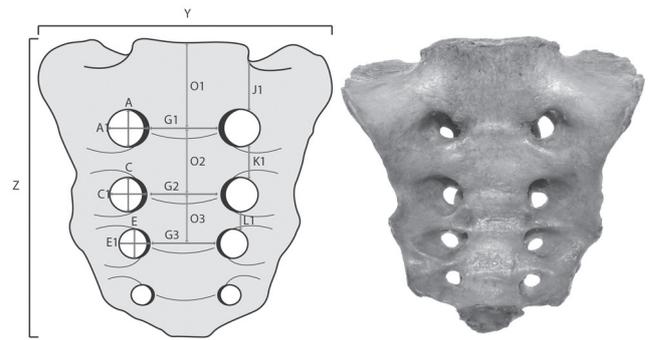
Figure 1. Linear measurements carried out in the anterior face of the sacrum.
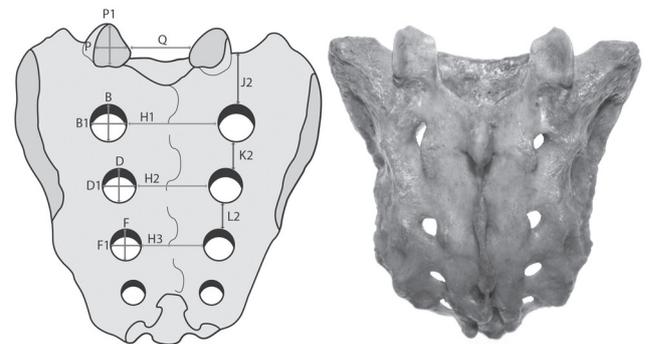
Figure 2. Linear measurements carried out in the posterior face of the sacrum.
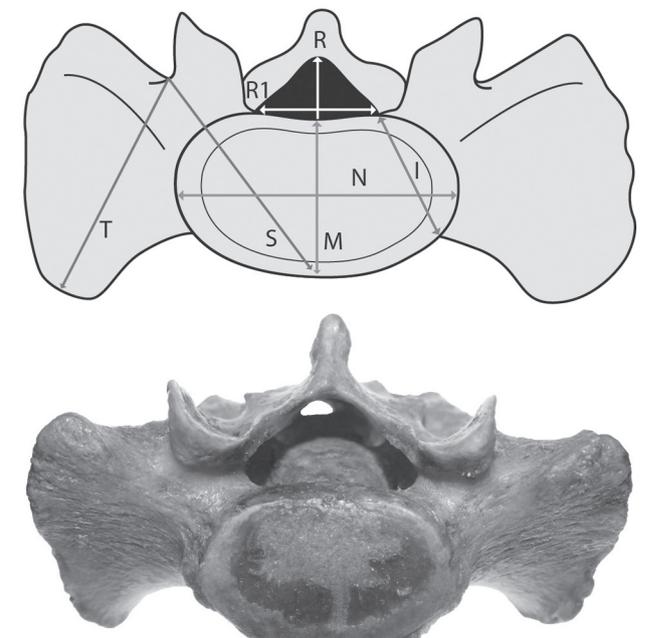
Figure 3. Linear measurements carried out in the superior face of the sacrum.

(parameter Z) of the sacrum (Figures 1 and 3). The antero-posterior diameter was defined as the distance between the anterior and posterior border of the superior surface of the body of the S1 vertebra. The transverse diameter is defined as the horizontal distance between both lateral borders of the S1 vertebra. S1 height was defined as the distance between the superior border of the S1 vertebral body and transverse line that represents the intervertebral disk obliterated between S1 and S2. The height of S2 and S3 was considered as the vertical distance between the corresponding transverse lines.

Category 4—Superior articular facet of S1 and sacral canal (parameters P-R1)

Included in this category were width (parameter P) and height (parameter P1) of the superior articular facet of S1, horizontal distance between both articular facets (parameter Q) and sagittal diameter (parameter R), and transverse (parameter R1) of the sacral canal at its superior opening (Figures 2 and 3).

Category 5—Approaches of the S1 pedicle (parameters S-X1)

Two measurements were carried out taking into consideration the point of entrance of the screw that represents its trajectory in the two approaches most commonly used, the first with direction towards the sacral promontory (anteromedial approach, parameter S) and the other towards the most anterolateral point of S1 wings (anteromedial approach, parameter T). The angles of the trajectory of the screws in the two approaches were determined in respect to an imaginary line running anteroposterior and at an acute angle to the trajectory of the screw (parameters V,W) as well as the angle of the screw on the anteromedial approach (parameter X) with respect to the midline (Figures 4 and 5). Likewise, the angle of the S1 articular facet with respect to an imaginary line that passes lateral to it was determined (parameter U) and the sagittal angle of the S1 pedicle (parameter XI) between an imaginary horizontal line that runs along the superior surface of S1 vertebral body and the anteromedial line of trajectory of the screw towards the sacral promontory.

Ethical Considerations

The protocol was approved by the Local Committee for Health Research with registration #AH12-001. No external funding was used and the authors declare no conflicts of interest.
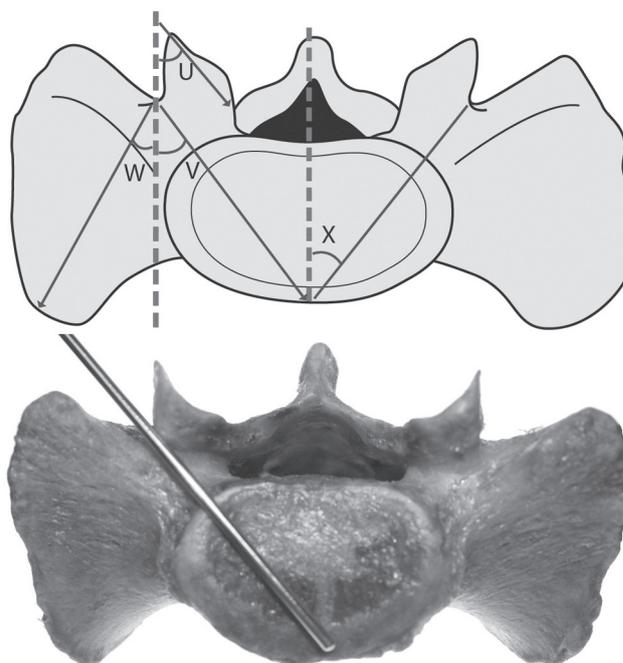
Figure 4. Angular measurements carried out in the superior face of the sacrum.
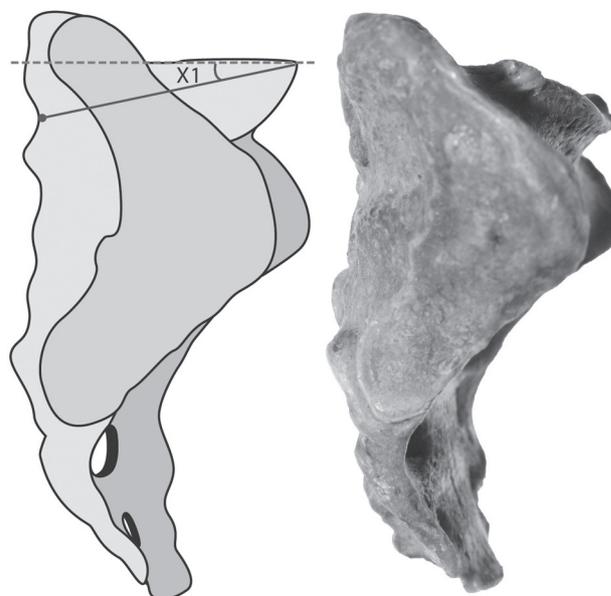
Figure 5. Angular measurements carried out in the lateral face of the sacrum**.**

Statistical Analysis

Measurement parameters were analyzed using Microsoft Office Excel 2010 for Windows. The mean and standard deviation for each of the measurement parameters is reported.

Results

Two independent observers studied 50 bilateral sacrums. The mean and the standard deviation for each measurement parameter of linear and angular distribution in the five categories mentioned above were obtained. All values were reported by category and displayed in tables.

Category 1—Anterior and posterior sacral foramina

The height and width of the first pair of anterior sacral foramina (parameters A and A1) were 13.66 mm ± 2.05 and 13.15 mm ± 2.88, respectively, with a horizontal distance of 32.33 mm ± 4.19 between them (Table 1).

Category 2—S1 vertebral pedicle and intermediate crests

The average length of the S1 pedicle (parameter I) was 25.00 mm ± 2.41. The average height of the anterior and posterior S1 pedicle (parameters J1 and J2) was 20.68 mm ± 3.40 and 24.64 mm ± 3.77, respectively (Table 2).

Category 3—Vertebral body and general sacral parameters

The mean of the anteroposterior and horizontal distances of the superior surface of the body of the S1 vertebra (parameters M and N) was 31.93 mm ± 2.91 and 48.72 mm ± 4.64, respectively, and the mean of the anterior height of the vertebral bodies (parameters O1-O3) was 31.11 mm ± 2.80 for S1, 25.06 mm ± 3.94 for S2 and 18.89 mm ± 2.63 for S3 (Table 2).

Category 4—Superior articular facet of S1 and sacral canal

The mean of the height and width of the facet joint (parameters P and P1) obtained in our study was 16.32 mm ± 2.12 and 16.37 mm ± 2.68, respectively. The mean dimension

Table 1. Morphometry of the first three pairs of anterior and posterior sacral foramina (Category 1)

Parameter	Left side		Right side		Average value	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
A	13.60	± 2.11	13.72	± 2.03	13.66	± 2.05
A1	13.28	± 2.67	13.02	± 3.11	13.15	± 2.88
B	11.38	± 2.66	11.42	± 2.52	11.40	± 2.58
B1	8.64	± 2.31	8.58	± 1.75	8.61	± 2.03
C	13.15	± 1.84	13.47	± 1.92	13.31	± 1.88
C1	13.91	± 2.74	14.01	± 2.39	13.96	± 2.55
D	7.66	± 1.35	7.54	± 1.40	7.60	± 1.37
D1	6.99	± 1.40	7.26	± 2.13	7.12	± 1.79
E	12.11	± 2.82	11.94	± 2.78	12.02	± 2.78
E1	13.51	± 3.31	13.40	± 3.21	13.46	± 3.24
F	6.99	± 2.26	6.40	± 2.07	6.70	± 2.17
F1	7.40	± 2.48	7.37	± 2.08	7.88	± 2.27
G1	–	–	–	–	32.33	± 4.19
G2	–	–	–	–	27.83	± 3.20
G3	–	–	–	–	25.89	± 2.37
H1	–	–	–	–	37.04	± 3.49
H2	–	–	–	–	31.76	± 3.43
H3	–	–	–	–	27.69	± 2.26

Mean and standard deviations (SD).

of the sacral canal at its superior aperture (parameters R and R1) was 15.13 mm ± 2.40 for the sagittal diameter and 31.07 mm ± 2.65 for the transverse diameter (Table 2).

Category 5—Approaches of the S1 pedicle

The mean distance from the screw entry point and the sacral promontory (S parameter) was 50.08 ± 3.72 mm with an angle to the midline (parameter X) of 42.20º ± 3.0 and an angle with respect to the superior surface the body of the S1 vertebra (parameter X1) of 20.10º ± 3.3 (Table 3).

Discussion

The sacrum and its components are the targets of fusion and fixation-instrumented lumbosacral procedures that are technically complex and labor-intensive and can generate many acute and chronic complications[3] among which are incorrect position of the screws, failure of the fixation system, stenosis of the segments adjacent to the fixation, neurological deficits, persistence and worsening of pain, persistent stenosis, ruptured transpedicular screws, peri-radicular fibrosis and neuropathic pain.[9] Numerous studies have been carried out in recent decades that highlight the importance of the precise knowledge of anatomy of the sacrum and its associated neighboring structures with the purpose of establishing safe surgical approaches during lumbosacral instrumentation to reduce morbidity and including mortality during and after these procedures. In the Mexican population there are no studies analyzing the morphometric characteristics of the sacrum.

Category 1—Anterior and posterior sacral foramen

The sacral foramina, especially the first three pairs, are part of a complex of channels with a "Y" shape where the ante-

Table 2. Morphometry of S1 vertebral pedicle and intermediate crests (Category 2), vertebral bodies S1-S3 (Category 3), superior articular facet of S1 and sacral canal in its upper opening (Category 4)

Parameter	Left side		Right side		Average value	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
Category 2. Vertebral pedicle of S1 and intermediate crests						
I	24.83	± 2.08	25.16	± 2.80	25.00	± 2.41
J1	20.84	± 3.48	20.51	± 3.37	20.68	± 3.40
J2	24.42	± 3.70	24.86	± 3.89	24.64	± 3.77
K1	12.70	± 2.95	12.43	± 3.01	12.56	± 2.97
K2	15.53	± 2.57	15.13	± 2.45	15.33	± 2.50
L1	7.09	± 1.65	7.15	± 1.79	7.12	± 1.71
L2	13.72	±1.97	13.58	± 2.03	13.65	±1.99
Category 3. Vertebral bodies and general parameters of the sacrum						
M	--	--	--	--	31.93	± 2.91
N	--	--	--	--	48.72	± 4.64
O1	--	--	--	--	31.11	± 2.80
O2	--	--	--	--	25.06	± 3.94
O3	--	--	--	--	18.89	± 2.63
Y	--	--	--	--	110.04	± 5.97
Z	--	--	--	--	97.49	± 7.16
Category 4. Superior articular facet of S1 and sacral canal						
P	16.40	± 2.19	16.24	± 2.08	16.32	± 2.12
P1	16.32	± 2.08	16.42	± 2.58	16.37	± 2.68
Q	–	–	–	–	25.74	± 4.17
R	–	–	–	–	15.13	± 2.40
R1	–	–	–	–	31.07	± 2.65

Mean and standard deviations (SD).

Table 3. Linear and angular measurements between the point of entry of the screw and reference points of the first sacral vertebra (Category 5)

Category 5. Approaches of the S1 pedicle					

Linear measurements:

Parameter	Left side		Right side		Average value	
	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)
S	49.82	± 3.88	50.34	± 3.49	50.08	± 3.72
T	50.33	± 4.37	51.06	± 3.41	50.57	± 3.93

Angular measurements

Parameter	Left side		Right side		Average value	
	Mean (grades)	SD (grades)	Mean (grades)	SD (grades)	Mean (grades)	SD (grades)
U	37.50	± 7.5	36.90	± 6.2	37.20	± 6.9
V	35.10	± 3.9	33.50	± 4.2	34.30	± 4.1
W	32.90	± 2.8	31.50	± 3.4	32.20	± 3.2
X	41.10	± 2.9	43.30	± 3.1	42.20	± 3.0
X1	19.70	± 3.7	20.50	± 3.2	20.10	± 3.3

Mean and standard deviations (SD).

rior sacral foramina represents the stem of the "Y", and the posterior foramina and intervertebral foramen represent the two branches of the "Y". Its content corresponds to the anterior and posterior roots of the sacral spinal nerves that exit the sacral canal through the intervertebral foramen. Lesions of the sacral foramen are easily ignored or confused and its identification is based mainly on knowledge of the normal anatomy of the structures that shape them.[10]

In the present study we found that the anterior and posterior sacral foramina decrease their size progressively distally, being the most important characteristic of the posterior sacral foramina. Based on these observations, the anterior and posterior sacral foramina have similar patterns of length and width.

Category 2—Vertebral pedicles and intermediate crests

In our study, the mean pedicle length was higher than that reported in other studies in other populations.[5-8,11,12] (Table 4). The posterior height of the S1 pedicle tends to be greater than its anterior height, which is important during screw insertion because it affects the ideal angulation it should take to avoid injury to the pedicular cortex.

Few studies have been cited in the literature that report the mean of the intermediate crests of S2 and S3.[13] In our study we observed that the height of the intermediate crests decreases in size distally, with this characteristic being more pronounced in the posterior height of the intermediate crests. The height of the posterior intermediate crests of S2 and S3 tends to be greater than its anterior height.

Category 3—Vertebral bodies and the general parameters of the sacrum

In our study, anteroposterior and horizontal distances of the superior surface of the body of the S1 vertebra show great similarity to those obtained by Arman et al.[6] in a Turkish population and Xu et al.[14] in a Chinese population (Table 5). The mean of the height of the S1, S2 and S3 vertebral bodies (parameters O1–O3) decreases distally. Ebraheim et al.,[8] in a morphometric study exclusive of S2, report an average value of 25.00 mm for the height of S2, with results similar to our study (25.06 mm). After consulting the literature, we found no reference to the height of S3 vertebral body. The width and height of the sacrum (parameters Y-Z) had the highest standard deviations in our study, demonstrating the great variability in both parameters among individuals.

Category 4—Superior articular facet of S1 and sacral canal

The mean of the height and width of the facet joint (parameters P and P1) are very close and their morphology is

Table 4. Vertebral pedicle of the first sacral vertebra

Study/Year/Population	Length of pedicle of S1 (mm)	Anterior height of pedicle of S1 (mm)	Posterior height of pedícle of S1 (mm)
Esenkaya et al. 2003,[11] Turkish	24.00 ± 2.6	---	---
Okutan et al. 2003,[5] Indian	22.50 ± 2.6	---	---
Olmos et al. 2002,[7] Spanish	21.30 ± 2.6	---	---
Arman et al. 2009,[6] Turkish	24.65 ± 3.84	---	---
Esses et al. 1991,[12] USA	---	26.10	30.20
Ebraheim et al. 1997,[8] European	---	22.70	23.07
Present study, Mexican	25.00 ± 2.41	20.68 ± 3.40	24.64 ± 3.77

Note: Average values obtained in specific populations.

Table 5. Vertebral body of the first sacral vertebra

Study/Year/Population	AP diameter of S1 body (mm)	T diameter of S1 body (mm)	Anterior height of S1 body (mm) S1 (mm)
Arman et al. 2009,[6] Turkey	31.42 ± 2.83	49.40 ± 5.89	30.22 ± 2.35
Xu et al. 1995,[14] Chinese	30.50 M / 29.30 F	45.40 M / 41.70 F	28.90 M / 22.70 F
Present study, Mexican	31.93 ± 2.91	48.72 ± 4.64	31.11 ± 2.80

Average values obtained in specific populations.
AP, anteroposterior; T, transverse; M, males; F, females.

almost squared. Arman et al.[6] obtained an average value of 14.62 mm ± 1.83 for height and 16.37 mm ± 2.14 for width of the superior articular facet of S1, results which are lower with respect to height and almost identical in regard to width. The dimensions of the sacral canal at its superior opening (parameters R and R1) were similar to those reported by Arman et al.[6] and Xu et al.[15] Arman et al.[6] reported values of 21.81 mm ± 3.66 and 31.31 mm ± 3.16 for the sagittal and transverse diameter, respectively, whereas Xu et al.[15] obtained average values of 12.30 mm for males and 12.20 mm for females with respect to the sagittal diameter and 27.50 mm for males and 26.40 mm for females relative to the transverse diameter. They reported no significant difference in this parameter with regard to gender; however, in accordance with the relationship that exists between both parameters it could be generally said that the sagittal diameter corresponds to 50–70% of the transverse diameter of the sacral canal at its superior aperture.

Category 5—Approaches of the S1 pedicle

During internal fusion and fixation procedures of the sacral spine, the approaches are considered to be safe if: *a)* the screw is inserted correctly at entry point; *b)* it has the appropriate length and *c)* it has the correct angulation. The results of our study broaden that which is reported in the literature by including measurements from the Mexican population. In our study, for an anteromedial approach of S1, the ideal length and angulation of the screw is 50.08 mm ± 3.72 and 34.30º ± 4.1, respectively, as well as with angle of 42.20 mm ± 3.0 with respect of the midline. The risks of placing a screw without taking into consideration the length and the adequate angle are *a)* penetration of the anterior cortex of S1, *b)* invasion of the medial wall of the anterior sacral foramen, *c)* causing injury to the spinal nerve or an adjacent vascular structure, and *d)* causing injury to the contents of the sacral canal.

In conclusion, the length of the S1 pedicle in Mexican populations was greater than that reported in other studies. The anterior and posterior heights of the S1 pedicle were 20.68 mm ± 3.40 and 24.64 mm ± 3.77, respectively. These values should be taken into consideration when choosing the size of the screw and placing it with less risk of causing damage. The anterior height of the vertebral bodies decreased in size distally. The mean of the anteroposterior and horizontal distances of the superior surface of the S1 vertebral body were 31.93 mm ± 2.91 and 48.72 mm ± 4.64, respectively. The superior articular facet of S1 had a square morphology. The sagittal diameter of the sacral canal is between 50 and 70% of its transverse diameter. On the anteromedial approach of S1, the length was 50.08 mm ± 3.72 with an angle with respect to the midline of 42.20º ± 3.0, and an angle with respect to an imaginary line that crosses perpendicular to the inferolateral surface of the superior articular facet of S1 was 34.30º ± 4.1. Morphometric characteristics of the sacrum in the Mexican population obtained by direct measurement in this study were similar to those reported by other studies in other populations. This information should be considered as a reference, but the vertebral anatomy should always be evaluated with preoperative computed tomography to establish a patient's individualized approach and avoid possible complications.

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