

# Morphometric Analysis of the Sacrum and its Surgical Implications

SANDEEP SALUJA<sup>1</sup>, SNEH AGARWAL<sup>2</sup>, ANITA TULI<sup>3</sup>, SHASHI RAHEJA<sup>4</sup>, SARIKA RACHEL TIGGA<sup>5</sup>, SHIPRA PAUL<sup>6</sup>

## ABSTRACT

**Introduction:** The predisposition of the human sacrum to a wide range of traumatic, degenerative and metastatic ailments demands frequent surgical interventions. For effective surgical management of these conditions, a comprehensive anatomical knowledge of the sacrum is mandatory but variability in morphometric dimensions exists amongst different population and precludes the standardisation of measurements.

**Aim:** To present a morphometric reference database for sacral instrumentation in Indian population and enable comparisons with other populations.

**Materials and Methods:** The study was performed on 108 adult human sacra. Linear measurements of the sacra were taken with the help of digital Vernier's calliper and angular parameters were determined with a goniometer.

**Results:** The morphometric analysis of the sacra of Indian population demonstrated that height and width of the first Anterior Sacral Foramina (ASF) were 12.97 mm and 12.23 mm respectively while height and width of the first Posterior Sacral Foramina (PSF) were 10.36 mm and 7.66 mm respectively. The

height and width of the second ASF were 12.85 mm and 13.13 mm respectively but the height and width of the second PSF were 7.05 mm and 7.30 mm respectively. Further, the anterior and posterior pedicle height were observed to be 20.74 mm and 20.18 mm respectively. Anteromedial and anterolateral screw trajectory distance were noted to be 45.67 mm and 44.60 mm respectively. The S1 pedicle depth was 23.48 mm but the S1 wing depth was 44.09 mm. Furthermore, there existed a highly significant difference ( $p < 0.001$ ) between the angular parameters of the right and left sides.

**Conclusion:** The height and width of the sacral foramina along with transverse distances between them were less in Indian sacra. Anterior pedicle height was observed to be greater in Indian sacra. However, posterior pedicle height was found to be lower than the values reported by other population. Additionally, the screw trajectory distances also displayed lower values in Indian population. Hence, present study signifies the application of screws of shorter length during sacral instrumentation as the morphometric dimensions are of lesser value in Indian population.

**Keywords:** Implants, Instrumentation, Screw trajectory angle, Screw trajectory distance

## INTRODUCTION

Sacrum is a large triangular fusion of five progressively smaller sacral vertebrae and their costal elements, maintaining the integrity of the spinal column [1]. It contributes to the stability of the pelvic ring by its situation, being wedged between the two hip bones and also endures weight transmission [2]. Sacrum is the target of lumbo-sacral fusion and instrumentation that are commonly done for metastatic, infectious, traumatic and degenerative diseases. Sacral screw insertion is commonly done at the S1 sacral wing (antero-laterally) or into the S1 promontory (antero-medially) [3]. S2 screw applications are usually chosen for sacral block fixations but rigid posterior S1 pedicle screw fixation enhanced by placement of S2 screws is becoming a common technique in lumbosacral fusion procedures [4,5].

Percutaneous fixation with ilio-sacral screws is a technically demanding technique and failure of sacral screw fixation may occur due to various factors, such as sacral anatomic variations and dysmorphism, insufficient sacral bone acquisition, inapt course of the screw or depth of the screw insertion and osteoporosis of the sacrum [3,4]. With the advance of minimally invasive surgical techniques, it is essential that the available implants are precontoured to the exact anatomical location which necessitates the comprehensive knowledge of morphometry of sacrum [6].

Differences exist in the morphometric values of sacrum across different study populations. So far, out of the studies available, few determine the morphometry of sacrum, especially in the Indian population. The present study was an attempt to quantify morphometric characteristics of the Indian sacra for safe screw

placement during surgical instrumentation which is crucial for constructing a strategy to treat sacrum related diseases in Indian population.

## MATERIALS AND METHODS

A cross-sectional observation study was conducted on 108 dry adult human sacra in Department of Anatomy. Sacra showing damage, bony outgrowth which influences differentiation or measurement were excluded from the study. Linear measurements were taken with the help of digital verniercaliper which was accurate up to 0.01 mm. Angles were measured by a goniometer which was accurate up to 1°. Measurements were taken twice and average was taken.

**The following parameters were observed and measured:**

### 1. Linear parameters [Table/Fig-1-4]

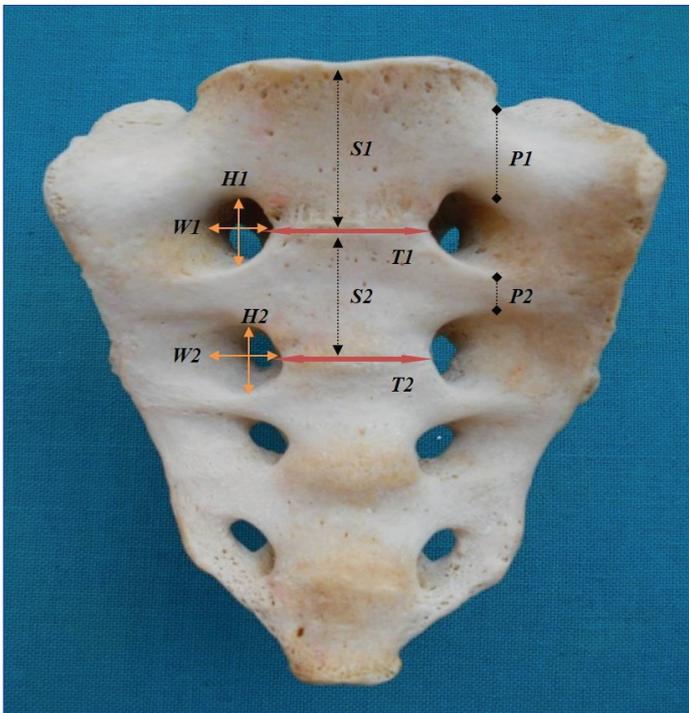
**Height of first Anterior Sacral Foramina (ASF):** Maximum vertical distance between the superior and inferior border of first anterior sacral foramen.

**Width of first ASF:** Maximum transverse distance between the medial and lateral border of first anterior sacral foramen.

**Height of first Posterior Sacral Foramina (PSF):** Maximum vertical distance between the superior and inferior border of first posterior sacral foramen.

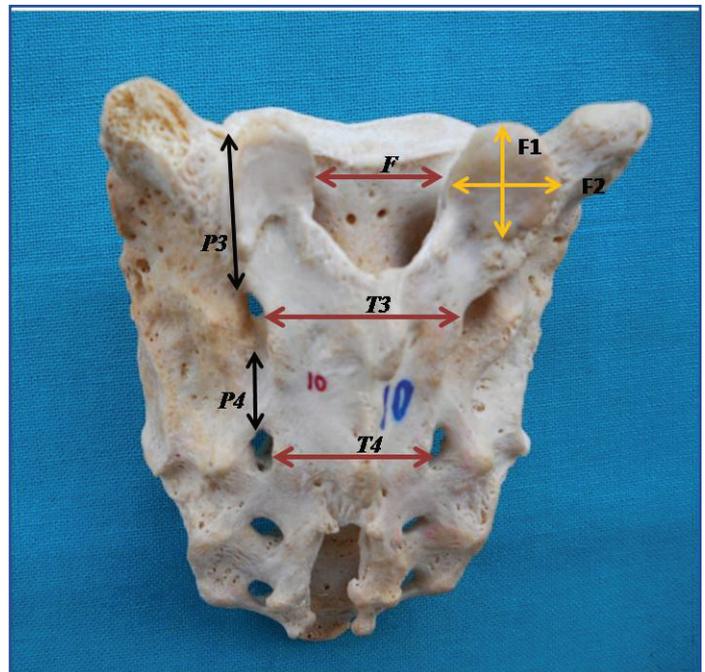
**Width of first PSF:** Maximum transverse distance between the medial and lateral border of first posterior sacral foramen.

**Height of second ASF:** Maximum vertical distance between the superior and inferior border of second anterior sacral foramen.



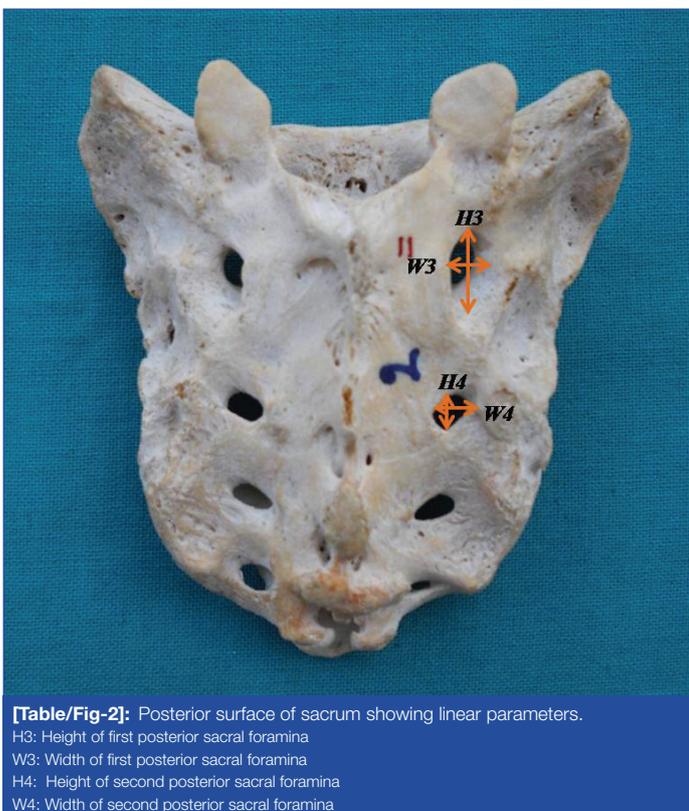
**[Table/Fig-1]:** Anterior surface of sacrum showing linear parameters.

- H1: Height of the first ASF
- W1: Width of the first ASF
- H2: Height of the second ASF
- W2: Width of the second ASF
- T1: Transverse distance between the first ASF
- T2: Transverse distance between the second ASF
- P1: Anterior pedicle height
- P2: Distance between the inferior border of the first ASF and the superior border of the second ASF
- S1: Height of the S1 vertebra body
- S2: Height of the S2 vertebra body



**[Table/Fig-3]:** Posterior surface of sacrum showing linear parameters.

- P3: Posterior pedicle height
- P4: Distance between the inferior border of the first PSF and the superior border of the second PSF
- T3: Transverse distance between the first PSF
- T4: Transverse distance between the second PSF
- F: Distance between the S1 facet joint
- F1: Height of S1 facet joint
- F2: Width of S1 facet joint



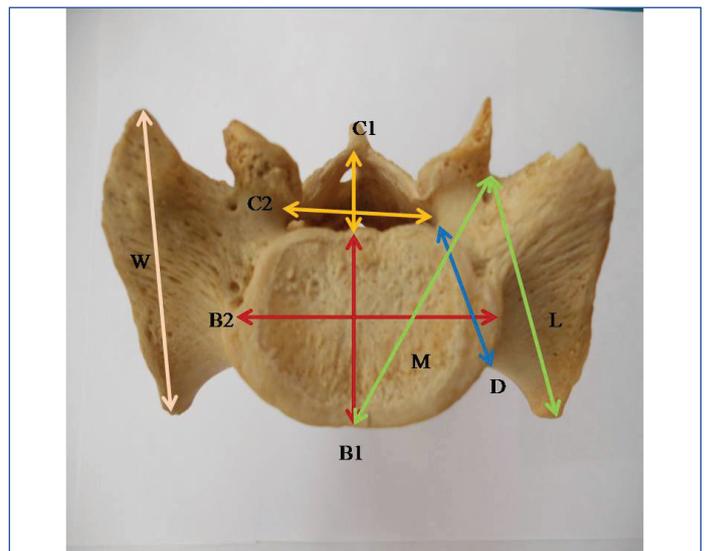
**[Table/Fig-2]:** Posterior surface of sacrum showing linear parameters.

- H3: Height of first posterior sacral foramina
- W3: Width of first posterior sacral foramina
- H4: Height of second posterior sacral foramina
- W4: Width of second posterior sacral foramina

**Width of second ASF:** Maximum transverse distance between the medial and lateral border of second anterior sacral foramen.

**Height of second PSF:** Maximum vertical distance between the superior and inferior border of second posterior sacral foramen.

**Width of second PSF:** Maximum transverse distance between the medial and lateral border of second posterior sacral foramen.



**[Table/Fig-4]:** Superior surface of sacrum showing linear parameters.

- C1: Sagittal diameter of the spinal canal
- C2: Transverse diameter of the spinal canal
- B1: S1 vertebral body APD
- B2: S1 vertebral body TD
- D: S1 pedicle depth
- M: Anteromedial STD
- L: Anterolateral STD
- W: Sacral wing depth

**Transverse distance between the first ASF:** Measured as the transverse distance between the two points on the medial border of first anterior sacral foramina at the level of first transverse fusion line between the first anterior sacral foramina.

**Transverse distance between the second ASF:** Measured as the transverse distance between two points on the medial border of second anterior sacral foramina at the level of second transverse fusion line between the second anterior sacral foramina.

**Transverse distance between the first PSF:** Measured as the transverse distance between the two points marked on the medial border of first posterior sacral foramina at the level of first articular tubercle.

**Transverse distance between the second PSF:** Measured as the transverse distance between two points marked on the medial border of second posterior sacral foramina at the level of second articular tubercle.

**Anterior pedicle height:** The vertical distance between the superior border of first anterior sacral foramen and the superior border of the sacrum.

**Distance between the inferior border of the first ASF and the superior border of the second ASF:** The vertical distance between the inferior border of first anterior sacral foramen and the superior border of the second anterior sacral foramen.

**Posterior pedicle height:** Measured as the vertical distance between the superior border of first posterior sacral foramen and the superior border of the sacrum.

**Distance between the inferior border of the first PSF and the superior border of the second PSF:** Measured as the vertical distance between the inferior border of first posterior sacral foramen and the superior border of the second posterior sacral foramen.

**Anteromedial Screw Trajectory Distance (STD):** The distance between the infero-lateral aspect of S1 facet joint and the antero-medial point of S1 vertebra (middle of the promontory).

**Anterolateral Screw Trajectory Distance (STD):** The distance between the infero-lateral aspect of S1 facet joint and the junction of anterior and lateral border of the ala of sacrum.

**S1 pedicle depth:** Measured as the minimal distance between the anterior and posterior borders of the pedicle.

**Sacral wing depth:** Measured as the maximum antero-posterior distance between the most posterior point of the ala of sacrum and a point on the anterior surface of the ala.

**Height of S1 facet joint:** The maximum vertical distance between the superior and inferior border of S1 facet.

**Width of S1 facet joint:** Measured as the maximum transverse distance between the medial and lateral borders of S1 facet.

**Distance between the S1 facet joints:** The maximum transverse distance between the medial borders of S1 facets.

**S1 vertebral body Antero-Posterior Diameter (APD):** Measured as the midline antero-posterior distance between the anterior and posterior borders of S1 vertebral body.

**S1 vertebral body Transverse Diameter (TD):** Measured as the maximum transverse distance of S1 vertebral body.

**Height of S1 vertebral body:** The vertical distance between the middle of promontory and the middle of first transverse fusion line between the first anterior sacral foramina.

**Height of S2 vertebral body:** The vertical distance between the middle of first transverse fusion line between the first anterior sacral foramina and middle of second transverse fusion line between the second anterior sacral foramina.

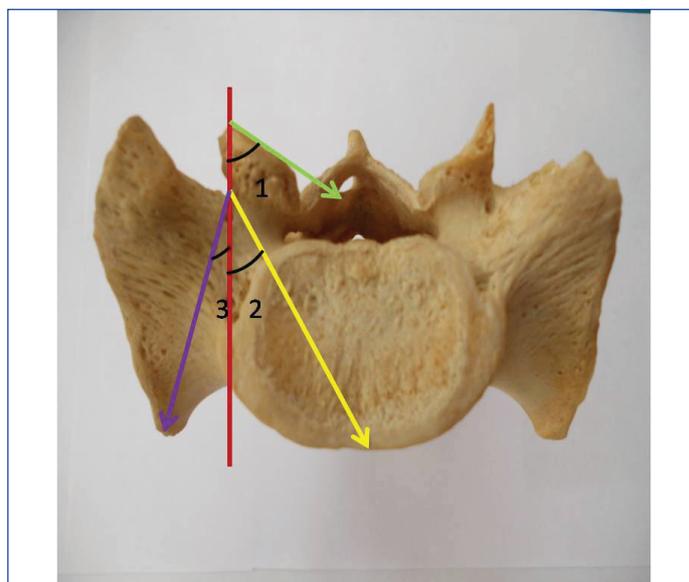
**Sagittal diameter of the spinal canal:** Measured as the midline antero-posterior distance between the anterior and posterior borders of superior aperture of sacral canal.

**Transverse diameter of the spinal canal:** Measured as the maximum transverse distance of the superior aperture of sacral canal.

## 2. Angular Parameters [Table/Fig 5]

**S1 facet angle:** Measured as the angle formed between the articular surface of S1 facet and an antero-posterior line passing through the S1 pedicle entry point.

**Anteromedial Screw Trajectory Angle (STA):** Measured as the angle formed between an antero-posterior line passing through the S1 pedicle entry point and a line passing from the S1 pedicle entry point to the midpoint of promontory.



[Table/Fig-5]: Superior surface of sacrum showing angular parameters.

1: S1 facet angle  
2: Anteromedial STA  
3: Anterolateral STA

**Anterolateral Screw Trajectory Angle (STA):** Measured as the angle formed between antero-posterior line passing through the S1 pedicle entry point and a line passing from the S1 pedicle entry point to the junction of anterior and lateral border of the ala of sacrum.

## STATISTICAL ANALYSIS

Statistical testing was conducted with the statistical package for the social science system version SPSS version 17.0. Results were expressed as mean±SD (standard deviation). The comparison of morphometric dimensions of the right and left sides was performed using Student's t-test and p-value was calculated.

## RESULTS

### Linear Parameters

The mean height and width of first ASF as well as height of the first PSF were comparable on both the sides but the width of the first PSF was found to be significantly greater on the right side. Furthermore, the height and width of the second ASF and second PSF were also analogous on both the sides. The height and width of the ASF were observed to be greater than the corresponding dimensions of the PSF. Although the transverse distances between the ASF were found to be lesser than the transverse distances between PSF [Table/Fig-6].

Mean anterior pedicle height of the sacrum was 20.74±2.29 mm which was significantly greater on the left side. Mean posterior pedicle height was also observed to be slightly more on the left side. Distance between the first ASF and second ASF as well as the distance between the first PSF and second PSF were comparable on both the sides. Anteromedial STD was slightly larger on the right side whereas anterolateral STD was almost similar on both the sides. Likewise, S1 pedicle depth and S1 wing depth were also observed to be comparable on both the sides. Width of S1 facet joint was more on the right side, though the height of the S1 facet joint was analogous on both the sides [Table/Fig-7].

### Angular Parameters

Mean S1 facet angle was 53.94±8.40 degree which was significantly larger on the left side. Anteromedial STA was also significantly greater on the left side but anterolateral STA was observed greater on the right side [Table/Fig-8].

Parameters	Right	Left	Mean value	p-value
Height of first ASF	12.95±1.65	12.99±1.59	12.97±1.03	0.702
Width of first ASF	12.28±1.69	12.18±1.80	12.23±1.63	0.40
Height of first PSF	10.40±2.75	10.32±2.67	10.36±2.63	0.47
Width of first PSF	7.81±1.54	7.51±1.41	7.66±1.37	0.005
Height of second ASF	12.75±1.85	12.95±1.84	12.85±1.76	0.056
Width of second ASF	13.11±2.05	13.15±2.15	13.13±2.01	0.77
Height of second PSF	7.03±1.56	7.06±1.56	7.05±1.47	0.80
Width of second PSF	7.34±1.49	7.27±1.47	7.30±1.39	0.49
TD between 1 <sup>st</sup> ASF	-	-	30.10±3.19	-
TD between 2 <sup>nd</sup> ASF	-	-	27.33±2.36	-
TD between 1 <sup>st</sup> PSF	-	-	37.49±3.90	-
TD between 2 <sup>nd</sup> PSF	-	-	30.47±3.18	-

**[Table/Fig-6]:** Morphometric measurements of sacral foramina (in mm).

Parameters	Right	Left	Mean value	p-value
Anterior Pedicle Height	20.40±2.39	21.07±2.43	20.74±2.29	<0.001
Distance between 1 <sup>st</sup> ASF and 2 <sup>nd</sup> ASF	11.39±2.25	11.26±2.38	11.33±2.24	0.28
Posterior Pedicle Height	20.05±2.37	20.30±2.54	20.18±2.36	0.06
Distance between 1 <sup>st</sup> PSF and 2 <sup>nd</sup> PSF	14.22±2.37	14.14±2.34	14.18±2.29	0.43
Anteromedial STD	45.79±3.51	45.56±3.49	45.67±3.44	0.06
Anterolateral STD	44.62±3.96	44.57±3.79	44.60±3.77	0.79
S1 pedicle depth	23.43±2.45	23.53±2.45	23.48±2.36	0.42
S1 wing Depth	44.02±4.85	44.16±4.95	44.09±4.83	0.40
Height of S1 facet joint	14.78±1.69	14.69±1.68	14.73±1.57	0.46
Width of S1 facet joint	15.72±1.88	15.49±2.12	15.61±1.86	0.09
Distance between S1 facet joint	-	-	25.46±3.53	-
S1 body APD	-	-	30.04±2.50	-
S1 body TD	-	-	47.64±4.98	-
Height of S1 body	-	-	29.62±2.65	-
Height of S2 body	-	-	25.45±2.41	-
Spinal canal SD	-	-	12.99±3.11	-
Spinal canal TD	-	-	29.33±2.76	-

**[Table/Fig-7]:** Morphometric measurements of sacrum (in mm).

Parameters	Right	Left	Mean value	p-value
S1 facet angle	52.55±9.02	55.32±9.16	53.94±8.40	<0.001
Anteromedial STA	35.13±2.95	36.0±2.66	35.56±2.63	<0.001
Anterolateral STA	32.18±3.09	30.67±2.75	31.42±2.75	<0.001

**[Table/Fig-8]:** Angular parameters of sacrum (in degrees).

## DISCUSSION

In the present study, we have attempted a comprehensive morphometric evaluation of sacra which can provide a reference database for designing customized sacral implants in Indian population. Such data also enables the comparison with other study populations and may serve as a tool for anthropological studies.

The dimensions (height and width) of the first and second ASF and PSF along with the transverse distances between these foramina were found to be less in our study as compared to Arman C et al., (Turkish population). In addition to importance in sacral instrumentation, these dimensions are crucial during electric stimulation of sacral nerve roots for modulating lower urinary tract neural reflexes in patients refractory to conventional treatment [Table/Fig-9,10] [3].

Mean anterior pedicle height was found to be greater in the Indian population (20.74 mm) than the findings in Turkish, Greek, Chinese and Egyptian population [3,7-10]. But Ebraheim NA et al., in American population reported higher value (30.2 mm) than ours [11].

Parameters (in mm)			Researchers	
			Arman C et al. [3]	Present study
1 <sup>st</sup> ASF	Height	Right	13.58±2.16	12.95±1.65
		Left	13.74±2.0	12.99±1.59
		Mean	13.66±2.11	12.97±1.62
	Width	Right	13.78±2.12	12.28±1.69
		Left	14.13±2.1	12.18±1.80
		Mean	13.95±2.12	12.23±1.74
1 <sup>st</sup> PSF	Height	Right	12.50±3.31	10.40±2.75
		Left	12.44±3.01	10.32±2.67
		Mean	12.47±3.16	10.36±2.70
	Width	Right	8.14±1.97	7.81±1.54
		Left	7.80±1.82	7.51±1.41
		Mean	7.97±1.89	7.66±1.48
2 <sup>nd</sup> ASF	Height	Right	13.48±2.26	12.75±1.85
		Left	13.72±1.98	12.95±1.84
		Mean	13.60±2.12	12.85±1.85
	Width	Right	13.97±2.69	13.11±2.05
		Left	14.46±2.27	13.15±2.15
		Mean	14.22±2.48	13.13±2.09
2 <sup>nd</sup> PSF	Height	Right	7.62±1.54	7.03-1.56
		Left	7.61±1.55	7.06-1.56
		Mean	7.62±1.54	7.05-1.56
	Width	Right	8.04±1.70	7.34±1.49
		Left	7.81±1.78	7.27±1.47
		Mean	7.92±1.74	7.30±1.48

**[Table/Fig-9]:** Comparison of morphometric measurements of sacrum between previous and present studies.

Parameters (in mm)	Researchers	
	Arman C et al., [3]	Present study
Transverse distance between 1 <sup>st</sup> ASF	30.48±2.78	30.10±3.19
Transverse distance between 2 <sup>nd</sup> ASF	28.31±2.81	27.33±2.36
Transverse distance between 1 <sup>st</sup> PSF	38.32±3.63	37.49±3.90
Transverse distance between 2 <sup>nd</sup> PSF	31.62±3.27	30.47±3.18

**[Table/Fig-10]:** Comparison of morphometric measurements of sacrum between previous and present studies.

Furthermore, the distance between the first and second ASF was also observed to be greater in the Indian population. However, the posterior pedicle height and the distance between 1<sup>st</sup> and 2<sup>nd</sup> PSF were noted to be less in our study when compared to other investigators. Injury to sacral nerve roots associated with posterior sacral screw placement during internal fixation and fusion procedures can be minimised if the pedicle heights are adequate. With adequate anterior pedicle height, there are less chances of violation of neurovascular structures anterior to the sacrum. Thus, we emphasise that posterior sacral screw placement during internal fixation in Indian population, may be much safer due to greater anterior pedicle height as it would allow for manipulation of the screw and chances of breaching anterior neurovascular structures would be reduced [Table/Fig-11]. There are two important screw trajectories for posterior sacral fixation, including the anteromedial STD and the anterolateral STD. In the present study, mean anteromedial STD was found to be 45.67±3.49 mm. It was observed that in the present study, values were not in conformity with other studies. Similarly mean anterolateral STD as per the present study was 44.60±3.87 mm while Arman C et al., reported 50.30±3.57 mm. Thus, present study suggests a prudent measure to employ screws of shorter length during lumbo-sacral fixation, than those used in the Turkish population [Table/Fig-11].

The mean S1 pedicle depth in present study was found to be 23.48±2.44 mm, while other researchers reported variable findings.

Mean sacral wing depth was  $44.09 \pm 4.89$  mm, which is less than values obtained by Arman C et al., ( $53.90 \pm 4.39$  mm). In the present study, findings do not corroborate with other researchers due to different populations under consideration and emphasise on the fact that Indian sacra are smaller in size, hence screws employed during lumbo-sacral fixation should be tailor made for Indian population [Table/Fig-12].

The dimensions of S1 facet play a central role in weight distribution and in prevention of spondylolisthesis. The mean height and width of S1 facet joint were  $14.73 \pm 1.68$  mm and  $15.61 \pm 2.0$  mm respectively, distance between S1 facet joints was  $25.46 \pm 3.53$  mm and our findings corroborate with Arman C et al., [Table/Fig-12].

The dimensions of the S1 body play a vital role during posterior lumbar body fusion and anterior lumbar body fusion procedures [3]. Furthermore, the knowledge of anatomy of S2 vertebra is crucial

during S2 lateral mass screw fixation which may intrude upon the iliac vessels or lumbosacral trunk while anchoring the anterior cortex of sacrum [12]. Arman C et al., reported higher values for the dimensions of S1 vertebra while Karachalios T et al., reported lower values than the present study. The height of S2 vertebral body was  $24.79 \pm 2.67$  mm according to present study and varied from the findings of other researchers [Table/Fig-12]. The sagittal diameter of spinal canal at superior aperture was found to be less than values obtained by other researchers and the transverse diameter was similar to study conducted by Hassanein GH. Reduced sacral spinal canal diameters may hinder lumbo-sacral procedures like thecaloscopy and play a crucial role in screw placement surgeries as the edge of the sacral canal forms the medial margin of the first sacral pedicle [10].

The STAs are of great significance as there is a risk of injury to neurovascular structures with poorly placed screws. Mirkovic S et al.,

Parameters (in mm)		Researchers (Population)						Present study
		Ebraheim NA et al., [11]	Arman C et al., [3]	Okutan O et al., [7]	Karachalios T et al., [8]	Liu W et al., [9]	Hassanein GH [10]	
		(American)	(Turkish)	(Turkish)	(Greek)	(Chinese)	(Egyptian)	
Anterior pedicle height	Right	-	$14.88 \pm 2.38$	-	19	-	-	$20.40 \pm 2.39$
	Left	-	$14.75 \pm 2.26$	-	19.5	-	-	$21.07 \pm 2.43$
	Mean	30.2	$14.81 \pm 2.32$	13.6	19.3	$18.1 \pm 3.8$	$18.3 \pm 4.9$	$20.74 \pm 2.42$
Distance between inferior border of 1 <sup>st</sup> ASF & superior border of 2 <sup>nd</sup> ASF	Right	-	$10.79 \pm 2.38$	-	-	-	-	$11.39 \pm 2.25$
	Left	-	$10.29 \pm 2.11$	-	-	-	-	$11.26 \pm 2.38$
	Mean	-	$10.54 \pm 2.25$	-	-	-	-	$11.33 \pm 2.31$
Posterior pedicle height	Right	-	$20.74 \pm 2.50$	-	-	-	-	$20.05 \pm 2.37$
	Left	-	$21.23 \pm 2.18$	-	-	-	-	$20.30 \pm 2.54$
	Mean	26.1	$20.98 \pm 2.34$	-	-	$20.6 \pm 3.6$	$23.8 \pm 5.0$	$20.18 \pm 2.45$
Distance between inferior border of 1 <sup>st</sup> PSF & superior border of 2 <sup>nd</sup> PSF	Right	-	$15.92 \pm 2.05$	-	-	-	-	$14.22 \pm 2.37$
	Left	-	$15.92 \pm 2.11$	-	-	-	-	$14.14 \pm 2.34$
	Mean	-	$15.92 \pm 2.08$	-	-	-	-	$14.18 \pm 2.35$
Anteromedial STD	Right	-	$51.12 \pm 4.83$	-	-	-	-	$45.79 \pm 3.51$
	Left	-	$51.26 \pm 4.72$	-	-	-	-	$45.56 \pm 3.49$
	Mean	-	$51.19 \pm 4.77$	-	-	-	$52.3 \pm 5.2$	$45.67 \pm 3.49$
Anterolateral STD	Right	-	$50.13 \pm 3.63$	-	-	-	-	$44.62 \pm 3.96$
	Left	-	$50.46 \pm 3.51$	-	-	-	-	$44.57 \pm 3.79$
	Mean	-	$50.30 \pm 3.57$	-	-	-	-	$44.60 \pm 3.87$

[Table/Fig-11]: Comparison of morphometric measurements of sacrum between previous and present studies.

Parameters (in mm)		Researchers (Population)					Present study	
		Ebraheim NA et al., [11] (American)	Arman C et al., [3] (Turkish)	Okutan O et al., [7] (Turkish)	Karachalios T et al., [8] (Greek)	Hassanein GH [10] (Egyptian)		
S1 pedicle depth	Right	-	$24.69 \pm 3.92$	-	18.2	-	$23.43 \pm 2.45$	
	Left	-	$24.60 \pm 3.75$	-	18.2	-	$23.53 \pm 2.45$	
	Mean	27.8	$24.65 \pm 3.84$	22.4	18.2	$29.9 \pm 5.3$	$23.48 \pm 2.44$	
Sacral wing depth	Right	-	$53.88 \pm 4.65$	-	-	-	$44.02 \pm 4.85$	
	Left	-	$53.92 \pm 4.12$	-	-	-	$44.16 \pm 4.95$	
	Mean	45.8	$53.90 \pm 4.39$	-	-	-	$44.09 \pm 4.89$	
S1 facet joint	Height	Right	-	$14.55 \pm 1.82$	-	-	-	$14.78 \pm 1.69$
		Left	-	$14.69 \pm 1.84$	-	-	-	$14.69 \pm 1.68$
		Mean	-	$14.62 \pm 1.83$	-	-	-	$14.73 \pm 1.68$
	Width	Right	-	$16.44 \pm 2.20$	-	-	-	$15.72 \pm 1.88$
		Left	-	$16.30 \pm 2.08$	-	-	-	$15.49 \pm 2.12$
		Mean	-	$16.37 \pm 2.14$	-	-	-	$15.61 \pm 2.0$
Distance between S1 facet joints	-	-	$25.68 \pm 3.80$	-	-	-	$25.46 \pm 3.53$	
S1 vertebral body diameter	A-P	-	-	$31.42 \pm 2.83$	-	25.17	-	$29.96 \pm 2.48$
Height of vertebral body	Transverse	-	-	$49.40 \pm 5.89$	-	-	-	$46.98 \pm 5.12$
	S1	-	-	$30.22 \pm 2.35$	-	27.8	-	$29.40 \pm 2.62$
Spinal canal diameter	S2	-	25.0	$26.34 \pm 6.09$	-	22.2	-	$24.79 \pm 2.67$
	Sagittal	-	-	$21.81 \pm 3.66$	-	-	$16.4 \pm 2.7$	$12.69 \pm 2.92$
	Transverse	-	-	$31.31 \pm 3.16$	-	-	$29.4 \pm 3.9$	$29.62 \pm 2.72$

[Table/Fig-12]: Comparison of morphometric measurements of sacrum between previous and present studies.

detected that the internal iliac vein and the lumbosacral nerve trunk were the most probable injured structure in front of the sacrum during screw placement at 30 and 45 degrees angulation. Sigmoid colon, in spite of being adjacent to the S2 screw, was shielded by its mesentery. Additionally, S1 pedicle screw placement was detected to be least likely affecting the neurovascular structures [13]. In the present study, the mean S1 facet angle was greater ( $53.94^\circ \pm 9.17$ ) than the finding of Arman C et al., ( $35.20^\circ \pm 9.62$ ) [3]. Thus, the increased angulation of the facets in Indian population is a normal finding in all probability and it may be due to diverse population habits which affect weight distribution. In the present study estimated mean anteromedial STA to be  $35.56^\circ \pm 2.83$  mm which was more than that obtained by Arman C et al., ( $33.80^\circ \pm 4.34$  mm) and anterolateral STA was almost similar in both studies. These above-mentioned angles are an important guide in pedicle screw placement at the sacrum and will allow characterisation of an optimal screw pathway in Indian population [Table/Fig-13].

Parameters (in degrees)		Researchers	
		Arman C et al., [3]	Present study
S1 facet angle	Right	$35.71^\circ \pm 9.5$	$52.55^\circ \pm 9.02$
	Left	$34.70^\circ \pm 9.66$	$55.32^\circ \pm 9.16$
	Mean	$35.20^\circ \pm 9.62$	$53.94^\circ \pm 9.17$
Anteromedial STA	Right	$35.65^\circ \pm 4.73$	$35.13^\circ \pm 2.95$
	Left	$31.95^\circ \pm 3.95$	$36.0^\circ \pm 2.66$
	Mean	$33.80^\circ \pm 4.34$	$35.56^\circ \pm 2.83$
Anterolateral STA	Right	$32.65^\circ \pm 3.51$	$32.18^\circ \pm 3.09$
	Left	$29.10^\circ \pm 3.14$	$30.67^\circ \pm 2.75$
	Mean	$30.87^\circ \pm 3.32$	$31.42^\circ \pm 3.02$

**[Table/Fig-13]:** Comparison of angular parameters of sacrum between previous and present studies.

Ultimately, the other Indian researchers observed analogous results for screw trajectory distances and S1 vertebral body diameters but other parameters were observed to be variable [14-16]. [Table/Fig-14] illustrates the comparison between different Indian studies and provides a range of each parameter for Indians which should be considered during operative procedures of lumbosacral region.

## LIMITATION

Present study was done on 108 dry adult human sacra due to limited availability in the institute. We propose further morphometric studies on large number of sacra to provide a reference database in Indian population.

## CONCLUSION

The lesser dimensions of sacral foramina and larger anterior pedicle height in Indian population indicate a greater margin of safety for screw placement in this region. In spite of this observation, we propose the application of shorter length screws, as screw trajectory distances of the Indian sacra are lesser compared to other populations. The present comprehensive study yielded the morphometric characteristics of the Indian sacra which can minimize visceral and neurovascular injury during transpedicular and lateral mass sacral screw placement.

Parameters	Researchers			
	Padmavathi Devi SV et al., [14]	Sinha MB et al., [15]	Murugesan ND and Dharmalingam M [16]	Present study
Anterior pedicle height	18.88 mm	-	21.09 mm	20.74 mm
Posterior pedicle height	-	19.42 mm	21.73 mm	20.18 mm
Pedicle depth	-	28.43 mm	-	23.48 mm
Anteromedial STD	45.11 mm	-	46.05 mm	45.67 mm
Anterolateral STD	44.9 mm	-	-	44.60 mm
S1 vertebral body APD	-	29.47 mm	-	29.96 mm
S1 vertebral body TD	-	46.02 mm	-	46.98 mm
Spinal Canal SD	-	11.95 mm	-	12.69 mm
Spinal canal TD	-	27.77 mm	-	29.62 mm
Anteromedial STA	$33.18^\circ$	-	$34.12^\circ$	$35.56^\circ$
Anterolateral STA	$26.95^\circ$	-	-	$31.42^\circ$

**[Table/Fig-14]:** Comparison of morphometric parameters of sacrum with other Indian studies.

## REFERENCES

- [1] Standring S, Newell RLM, editors. Gray's Anatomy: The anatomical basis of clinical practice. 40<sup>th</sup> ed. Spain: Churchill Livingstone Elsevier; 2008.
- [2] Pal GP. Weight transmission through the sacrum in man. *J Anat.* 1989;162:09-17.
- [3] Arman C, Naderi S, Kiray A, Aksu FT, Yilmaz HS, Tetic S, et al. The human sacrum and safe approaches for screw placement. *Journal of Clinical Neuroscience.* 2009;16(8):1046-49.
- [4] Ergur I, Akcali O, Kiray A, Kosay C, Tayefi H. Neurovascular risks of sacral screws with bicortical purchase: an anatomical study. *Eur Spine J.* 2007;16(9):1519-23.
- [5] Kwan MK, Jeffrey A, Chan CY, Saw LB. A radiological evaluation of the morphometry and safety of S1, S2 and S2-iliac screws in the Asian population using three dimensional computed tomography scan: an analysis of 180 pelvis. *Surg Radiol Anat.* 2012;34(3):217-27.
- [6] Liao SH, Tong RF, Tang M. Computer aided design and evaluation of new anatomic fixation system on entire pelvic model. 2009 SIAM/ACM Joint Conference on Geometric and Physical Modeling; 2009 Oct 4-9; San Francisco, California. New York, USA: ACM; 2009. Pp. 331-336.
- [7] Okutan O, Kaptanoglu E, Solaroglu I, Beskonakli E, Tekdemir I. Pedicle morphology of the first sacral vertebra. *Neuroanatomy.* 2003;2:16-19.
- [8] Karachalios T, Zibis AH, Zintzaras E, Bargiotas K, Karantanis AH, Malizos KN. An anatomical update on the morphologic variations of S1 and S2. *Orthopedics.* 2010;33(10):733.
- [9] Liu W, Du XR, Yang LH, Wang R, Zhang JZ, Kong XC, et al. The treatment of lumbosacral transitional vertebra using sacroiliac screws: clinical anatomic survey. *Chinese Journal of Clinical Anatomy.* 2011;29(5):520-23.
- [10] Hassanein GH. Metric study of Egyptian sacrum for lumbo-sacral fixation procedures. *Clin Anat.* 2011;24(2):218-24.
- [11] Ebraheim NA, Xu R, Biyani A, Nadaud MC. Morphologic considerations of the first sacral pedicle for iliosacral screw placement. *Spine.* 1997;22(8):841-46.
- [12] Ebraheim NA, Lu J, Yang H, Heck BE, Yeasting RA. Anatomic considerations of the second sacral vertebra and dorsal screw placement. *Surg Radiol Anat.* 1997;19(6):353-57.
- [13] Mirkovic S, Abitbol JJ, Steinman J, Edwards CC, Schaffler M, Massie J, et al. Anatomic consideration for sacral screw placement. *Spine.* 1991;16(6S):S289-94.
- [14] Padmavathi Devi SV, Rajini T, Mokhasi V. Morphometry of the first sacral pedicle in South Indian population. *International Journal of Current Research and Review.* 2014;6(13):38-44.
- [15] Sinha MB, Mrithunjay R, Soumitra T, Siddiqui AU. Morphometry of first pedicle of sacrum and its clinical relevance. *International J of Healthcare & Biomedical Research.* 2013;1(4):234-40.
- [16] Murugesan ND, Dharmalingam M. First sacral pedicle—a morphometric analysis. *Indian Journal of Clinical Anatomy and Physiology.* 2016;3(1):30-33.

### PARTICULARS OF CONTRIBUTORS:

1. Assistant Professor, Department of Anatomy, G S Medical College and Hospital, Pilkhuwa, Hapur, Uttar Pradesh, India.
2. Director Professor, Department of Anatomy, Lady Hardinge Medical College and Associated Hospitals, New Delhi, India.
3. Director Professor, Department of Anatomy, Lady Hardinge Medical College and Associated Hospitals, New Delhi, India.
4. Director Professor, Department of Anatomy, Lady Hardinge Medical College and Associated Hospitals, New Delhi, India.
5. Assistant Professor, Department of Anatomy, ESIC Medical College and Hospital, Faridabad, Haryana, India.
6. Director Professor, Department of Anatomy, Lady Hardinge Medical College and Associated Hospitals, New Delhi, India.

### NAME, ADDRESS, E-MAIL ID OF THE CORRESPONDING AUTHOR:

Dr. Sarika Rachel Tigga,  
Assistant Professor, Department of Anatomy, ESIC Medical College and Hospital, NH-3, NIT, Faridabad, Haryana, India.  
E-Mail: sarika.rachel@gmail.com

Date of Submission: **Sep 28, 2017**

Date of Peer Review: **Nov 23, 2017**

Date of Acceptance: **Apr 03, 2018**

Date of Publishing: **Jun 01, 2018**

FINANCIAL OR OTHER COMPETING INTERESTS: None.