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A Computed Tomography-Based Assessment of the Anatomical Parameters Concerning S2-Alar Iliac Screw Insertion Using "Safe Trajectory Method" in Indian Population

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Study Design: A retrospective computed tomography (CT)-based radiological analysis.

Purpose: To obtain CT-based morphometric data for the S2 alar iliac (S2AI) screw in the Indian population presenting to School of Medical Sciences and Research, Greater Noida, we used the concept of "safe trajectory" by Pontes and his colleagues in a recent study.

Overview of Literature: Although previous CT-based morphometric studies on the S2AI screw have been published for a variety of ethnic groups, morphometric data specifically for the Indian population are scarce.

Methods: We used the three-dimensional multiplanar reformatting software to conduct a retrospective CT analysis of 112 consecutive patients who met our exclusion criteria for various abdominal and pelvic pathologies. CT imaging planes were rotated between the S1 and S2 foramen until they matched the ideal S2AI screw trajectory, which was represented by the longest and widest iliac osseous channel observed in the axial CT section. Following the concept of a safe trajectory, S2AI screw morphometric parameters were measured on both sides of the pelvis using corresponding axial and sagittal CT images.

Results: In the sagittal and transverse planes on both sides of the pelvis, females had significantly higher screw trajectory angulation than males (p<0.001). On both sides of the pelvis, males had significantly greater iliac width, maximum screw trajectory length, and intrascrotal length than females (p<0.001). On both sides of the pelvis, the S2AI screw entry point in females was significantly deeper than in males from the skin margin (p<0.001).

Conclusions: Based on our methodology, we discovered that the S2AI screw trajectory is significantly more caudal and lateral in females, the maximum screw length is sufficient for use in clinical practice regardless of gender, and that 8.5 mm or even larger screw diameters are feasible in the majority of the Indian population.

Keywords: S2 alar iliac screw; Indian population; Safe trajectory; Computed tomography

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Introduction

The lumbosacral junction is a complex anatomical region with extremely high shear forces, making long spinal fusion procedures across it extremely difficult, resulting in significant complications, such as pseudoarthrosis and implant failure [1]. The indications for spinopelvic fixation involving lumbosacral junction include high-grade spondylolisthesis; long spinal fusion procedures for pediatric or adult spinal deformities due to various causes, especially with pelvic obliquity; three-column corrective lumbar osteotomies; lumbopelvic trauma; pseudoarthrosis due to prior surgery; and lower lumbar spine spondylectomy or gastrectomy for tumors or infections [2].

Over the years, several techniques for spinopelvic fixation have been described in the literature, but the iliac screw (IS) and S2 alar iliac screw (S2AI) are the most commonly used. Although the IS placed at the level of the posterior superior iliac spine provides significant pullout strength, a significant soft tissue dissection is required for screw insertion, and the offset connector is required for attachment to the spinal construct rod, resulting in an increased risk of wound complications and hardware prominence [3]. To overcome these drawbacks of the IS, Sponseller and Kebaish in 2007 proposed the S2AI screw technique [4]. The advantage of this technique is that S2AI is inserted at the same level as the S1 pedicle screw, resulting in less soft tissue dissection and eliminating the need for a lateral offset connector. S2AI is implanted much deeper than IS, resulting in less hardware prominence, wound dehiscence, and postoperative pain [5].

Although there is a paucity of data exclusively focused on the Indian population in the existing literature, computed tomography (CT)-based morphometric data concerning the S2AI screw insertion technique in the American, Asian, and Brazilian populations has been published [6-11]. In the existing literature, studies have highlighted the fact that a patient's ethnicity may influence the trajectory and length of the S2AI screw [12]. Prior studies evaluated S2AI screw morphometric data based on ideal screw trajectory, which represented the greatest length and width of the iliac osseous channel obtained after the rotation of CT image planes [6-8,10,11]. Pontes et al. [13] recently proposed a safe S2AI screw trajectory to prevent iliac wing cortical violation, which can lead to catastrophic neurovascular complications. The safe trajectory is defined as the axis of the S2AI screw path with reference to the inner iliac cortex at the iliac width region, which corresponds to the narrowest portion of the iliac wing, at a distance equal to half the screw's internal diameter [13]. We prefer to support their concept, and as part of our methodology, we performed a CT-based evaluation at our institution with the aim of measuring morphometric parameters related to the S2AI screw in the Indian population.

Materials and Methods

Approval was obtained from the ethics committee of School of Medical Sciences and Research, Sharda University before the present study was conducted (SU/SMS&R/76-A/2021/93). A retrospective review of the CT scans performed for patients with various abdominal and pelvic pathologies from December 2019 to March 2020 was conducted. The images used in this study were anonymized. Because this is a retrospective study, informed consent could not be obtained; thus, the ethics committee of School of Medical Sciences and Research, Sharda University granted a waiver. Data of 112 consecutive patients were collected following our exclusion criteria, which included age less than 18 years, prior surgery involving pelvis or lumbosacral region, transitional lumbosacral anomalies, any prior sacropelvic segment pathology (trauma, infection, tumor, congenital abnormality, ankylosing spondylitis), and any pelvic deformity. All CT images from each patient were retrieved from Picture Archiving and Communication System and analyzed using the Radiant DICOM viewer software ver. 72 5.0.0.219060 (Medixant, Poznań, Poland), with a dedicated window for bone structures. As per prior published studies, initially, images along the sagittal and coronal planes for the pelvis were reconstructed using the three-dimensional multiplanar reformatting software function. The CT imaging plane was then moved along the mid-sagittal reconstruction image to a point between the S1 and S2 foramens using the coronal image for guidance. Subsequently, the CT image plane along the sagittal axis was rotated until it corresponded to the ideal S2AI screw trajectory, which was represented by the greatest length and width of the iliac osseous channel observed in the axial CT image at that level. The S2AI screw entry point was marked along the posterior sacral cortex in an axial CT image, which was aided in the localization of the point by the coronal plane image (Fig. 1A, B) [13]. As per the existing literature, we selected the screw

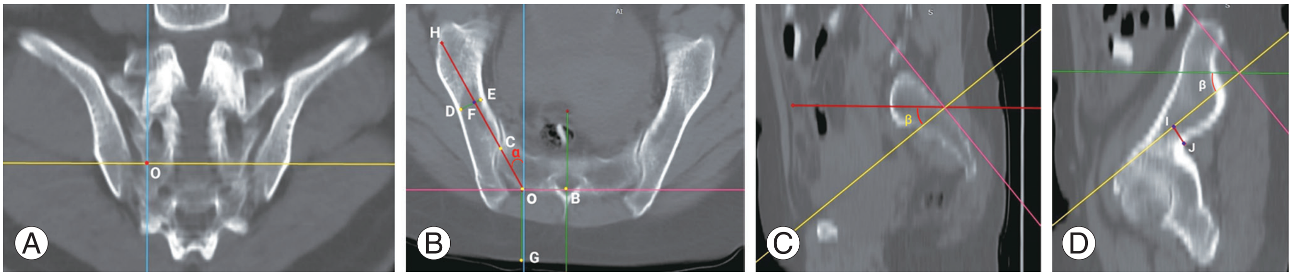

Fig. 1. Reconstructed computed tomography (CT) images using three-dimensional multiplanar reconstruction function following sagittal plane axis rotation to achieve ideal screw trajectory. **(A)** coronal plane CT image with point "O" as a screw entry point. **(B)** Axial plane CT image with point "O" as screw entry point corresponding with the coronal plane image (α: transverse plane angle of screw trajectory; OH: maximum screw trajectory length; OC: sacral distance; OB: S2 midline distance; ED: iliac width; EF: distance equal to half the internal diameter of the chosen screw). **(C, D)** Sagittal plane images (β: sagittal plane angle of screw trajectory; IJ: sciatic notch distance).

entry point at the junction of two lines: first along the lateral sacral crest and second along the middle of the S1 and S2 foramens [14]. The iliac width, which determines the largest possible screw diameter, was then marked by measuring the distance between the inner and outer cortices of the iliac wing. According to the safe trajectory concept, a point was marked along the iliac width line with reference to the inner iliac cortex, and the distance between these two points was half the inner diameter of the selected screw [13]. We selected screw diameters of 6.5, 7.5, and 8.5 mm for measurement purposes as they are commonly used as per existing literature [15]. Depending on the iliac width, the selected screw diameters were as follows: 6.5 mm for width <7.5 mm, 7.5 mm for width ≥7.5 mm but <8.5 mm, and 8.5 mm for width ≥8.5 mm. Finally, the screw trajectory toward the anterior iliac cortex was marked between two points, the posterior S2 sacral cortex entry point and the iliac width line, and the following parameters were measured (Fig. 1B–D): (1) sagittal angle (β): caudal angle between screw trajectory along the sagittal plane and horizontal line; (2) transverse angle (α): angle between the lateral screw trajectory and median line along the axial plane; (3) maximum length (OH): maximum length of the screw trajectory along the axial plane from the posterior sacral cortex entry point to the anterior iliac cortex; (4) sacral length (OC): length of the intrascrotal screw trajectory along the axial plane; (5) iliac width (ED): narrowest iliac wing portion represented by the shortest distance between the inner and outer iliac wing cortices; (6) S2 midline distance (OB): distance between the posterior sacral screw entry point and line along the middle of the S2 vertebrae; (7) skin distance (OG): distance between the posterior sacral screw entry point and skin margin; and (8) sciatic notch distance (IJ): minimum distance between the greater sciatic notch and screw trajectory along the sagittal plane.

A senior spinal surgeon and a senior radiologist independently performed CT-based morphometric measurements of the aforementioned S2AI screw parameters, and the average of the measurements noted by two reviewers was then recorded. Subsequently, the recorded data were subjected to statistical analysis using IBM SPSS Statistics for Mac ver. 25.0 (IBM Corp., Armonk, NY, USA). The continuous variables were expressed as mean±standard deviation (SD). The statistically significant difference between the right and left sides of each gender was determined using a paired *t*-test. An independent *t*-test was employed to find the differences in the parameters between males and females. A p-value of <0.05 indicated a significant difference for all statistical data analyses.

Results

The present study evaluated the CT records of 112 patients (58 [51.8%] males and 54 [48.2%] females). The mean age was 36.79 years (SD=13.67; range, 18–77 years). As presented in Table 1, no significant differences were observed in the measured parameters between the right and left sides of each gender. On the analysis of morphometric data between genders, as presented in Table 2, the measured sagittal plane angulation of the S2AI screw trajectory in females (right: 38.02°±6.06°; left: 37.28°±6.14°) was significantly higher than that in males (right: 31.25°±6.58°; left: 31.04°±6.70°) (p<0.001). Also in the transverse plane, the lateral angulation of the screw trajectory in females (right: 36.87°±3.64°; left: 36.78°±3.34°) was significantly higher than that in males (right: 34.92°±3.31°; left: 35.03°±3.54°) (p<0.001). With

Table 1. Distribution of measuring parameters between the right side and left side for each gender (N=112)

Variable	Males (N=58)			Females (N=54)		
	Right side	Left side	*p*-value	Right side	Left side	*p*-value
Sagittal angle (°)	31.25±6.58	31.04±6.70	0.476	38.02±6.06	37.28±6.14	0.114
Transverse angle (°)	34.91±3.31	34.96±3.53	0.814	36.87±3.64	36.86±3.33	0.935
Maximum length (mm)	112.86±7.65	112.83±7.62	0.868	105.72±7.76	106.00±7.54	0.233
Sacral length (mm)	27.28±3.82	27.22±3.58	0.700	25.41±3.72	25.34±3.69	0.710
S2 midline distance (mm)	29.08±2.62	29.32±5.62	0.730	29.66±2.29	29.42±2.65	0.570
Skin distance (mm)	42.66±15.20	42.76±15.19	0.642	52.48±16.75	52.20±16.73	0.223
Iliac width (mm)	14.77±2.88	14.92±2.75	0.323	12.53±2.32	12.46±2.21	0.580
Sciatic notch distance (mm)	16.34±2.52	16.19±2.45	0.450	16.49±2.28	16.15±1.93	0.109

Values are presented as mean±standard deviation.

Table 2. Comparison of measured parameters between gender (males versus females)

Variable	Right side			Left side		
	Males	Females	*p*-value	Males	Females	*p*-value
Sagittal angle (°)	31.25±6.58	38.02±6.06	<0.001	31.04±6.70	37.28±6.14	<0.001
Transverse angle (°)	34.92±3.31	36.87±3.64	<0.001	35.03±3.54	36.78±3.34	<0.001
Maximum length (mm)	112.86±7.65	105.71±7.76	<0.001	112.83±7.62	106.00±7.54	<0.001
Sacral length (mm)	27.28±3.82	25.41±3.72	<0.001	27.22±3.58	25.34±3.69	<0.001
S2 midline distance (mm)	29.08±2.62	29.66±2.29	0.218	29.32±5.62	29.42±2.65	0.902
Skin distance (mm)	42.66±15.20	52.90±16.63	<0.001	42.76±15.19	52.20±16.73	<0.001
Iliac width (mm)	14.77±2.88	12.53±2.32	<0.001	14.92±2.75	12.46±2.21	<0.001
Sciatic notch distance (mm)	16.34±2.52	16.49±2.28	0.750	16.19±2.45	16.15±1.93	0.924

Values are presented as mean±standard deviation.

regard to the length parameters of the screw trajectory involving maximum length (OH) and intrasacral length (OC), both parameters were significantly higher in males (OH, right: 112.86±7.65 mm; left: 112.83±7.62 mm) (OC, right: 27.28±3.82 mm; left: 27.22±3.58 mm) than in females (OH, right: 105.71±7.76 mm; left: 106.00±7.54 mm) (OC, right: 25.41±3.72 mm; left: 25.34±3.69 mm) (p<0.001). The iliac width was significantly narrower in females (right: 12.53±2.32 mm; left: 12.46±2.21 mm) than in males (right: 14.77±2.88 mm; left: 14.92±2.75 mm) (p<0.001). The screw entry point was significantly more deep-seated from the overlying skin margin in females (right: 52.90±16.63 mm; left: 52.20±16.73 mm) than in males (right: 42.66±15.20 mm; left: 42.76±15.19 mm) (p<0.001). The midline distance of the screw entry point and the distance between the sciatic notch were not significantly different between genders on both sides.

Discussion

A thorough understanding of anatomy before performing any surgical technique helps the surgeons improve their surgical skills and reduce complications [16]. Previous morphometric studies comparing the Indian population with other ethnic groups revealed significant differences in the spinal parameters [17,18]. Even concerning the S2AI screw, Katsuura et al. proposed that the patient's ethnicity may have an influence on the screw trajectory and length [12]. We decided to evaluate morphometric data on S2AI insertion based on these facts and the lack of any data specifically focused on the Indian population in the existing literature.

The iliac cortical violation caused by the oversize screw channel or the overtilted screw trajectory, especially at the iliac width region, which represents the narrowest portion of the iliac wing, is one of the major risks associated with the S2AI screw technique. This may lead to catastrophic complications such as visceral injuries involving the intestines and urogenital organs and neurovascular injuries involving the internal iliac vessels, superior gluteal artery, lumbosacral plexus, obturator nerve, and sciatic nerve [19]. Pontes et al. [13] proposed the concept of a safe trajectory to avoid such serious complications, which we adopted in our current morphometric study of the S2AI screw in the Indian population. We believe that the distance between the inner iliac cortex and screw trajectory at the iliac width region, which is equivalent to half the diameter of the selected screw, will provide a safety margin in preventing cortical violation resulting in catastrophic complications.

On the comparison of the iliac width measurements with data from other ethnic populations, our study results indicated narrower width in comparison with the Chinese (Zhu et al. [8]: right 17±2.81 mm/left 16.98±3.52 mm in males and right 14.94±2.60 mm/left 14.76±2.46 mm in females; Li et al. [7]: right 17.8±3.3 mm/left 17.5±3.4 mm in males and right 15.5±2.9 mm/left 15.3±2.6 mm in females), Japanese (Yamada et al. [11]: right 18.5±3.7 mm/left 18.1±3.4 mm in males and right 16±3.1 mm/left 15.9±2.8 mm in females), and Brazilian (Tavares Junior et al. [10]: 17.94±2.34 mm) populations. Males had a wider iliac width than females in the current study, which is similar to the pattern observed in the Chinese and Japanese populations [7,8,11]. According to previous literature, three screw diameters were selected for measurement purposes based on the iliac width: 6.5, 7.5, and 8.5 mm as the largest diameter [15]. Only 3.57% of the cases (three females and one male) of our study population had an inadequate iliac width for the 8.5-mm screw diameter. As per prior studies, the bending strength of a screw increases proportionately to its radius to the fourth power. Although no ideal S2AI screw diameter has been recommended in the adult population in the current literature, Jain et al. [20] proposed that the ideal diameter for preventing screw fracture in the pediatric population is >8 mm. Based on our study results regarding the iliac width (average of 14 mm in males and 12 mm in females), our opinion is that a screw diameter of 8.5 mm and even more may be feasible in the majority of the Indian population [20].

With regard to the maximum screw trajectory length, those obtained in our study were shorter than that observed in the Chinese (Zhu et al. [8]: right 120.63±7.54 mm/left 121.25±8.33 mm in males and right 115.67±8.24 mm/left 114.75±9.44 mm in females; Li et al. [7]: right 121.2±8.8 mm/left 121.4±9.3 mm in males and right 114.2±8.7 mm/left 114.3±9.5 mm in females), Japanese (Yamada et al. [11]: right 121.8±10.1 mm/left 121.5±10.3 mm in males and right 112.7±9.1 mm/left 113.8±9.6 mm in females), and Brazilian (Tavares Junior et al. [10]: 133.67±9.89 mm) populations. When gender differences were considered, the males in our study had significantly longer screws than females, which is similar to the pattern observed in the Chinese and Japanese populations [7,8,11]. The difference in the maximum screw length in our study compared with other ethnic populations could be due to our research methodology, which causes the screw trajectory to drift away from the inner iliac cortex by a distance equal to half the inner screw diameter of the selected screw, depending on the iliac width, to avoid cortical violation. As pointed out by Pontes et al. [13], the closer the screw trajectory to the inner iliac cortex in the axial plane, the longer the screw length. In our study, the average screw lengths were 112 nm and 106 nm for males and females, respectively, which were still longer than that commonly used by surgeons in clinical practice (approximately 50–75 mm) according to the literature [21]. According to a study by O'Brien et al. [22] on the biomechanical evaluation of the S2AI screw, the authors concluded that the 65-mm-length S2AI screw is biomechanically equivalent to 90-mm IS and 80-mm S2AI screw. They proposed that the IS screw trajectory primarily passes through the spongy iliac bone, whereas the S2AI screw trajectory involves cortical penetration of the sacroiliac joint, which results in increased strength despite its shorter length [22]. In our opinion, a possible trade-off between screw length and screw safety is worth considering, which can be confirmed in the future by clinical studies.

On the comparison of the sagittal angulation of the S2AI screw trajectory, our study results indicated higher sagittal angulation than that in the Chinese (Zhu et al. [8]: right 29.96°±8.28°/left 29.15°±8.60° in males and right 35.72°±7.53°/left 34.5°±6.56° in females; Li et al. [7]: right 29°±7.4°/left 28.3°±7.7° in males and right 34.8°±7.1°/left 33.9°±6.5° in females), Japanese (Yamada et al. [11]: right 28°±7.2°/left 27.5°±6.8° in males and right 33.9°±6.6°/left 33.4°±6.4° in females), and Brazilian (Tavares Junior et al. [10]: 29.92°±2.33°) populations. Females had higher sagittal angulation than males when gender differences were considered, similar to the pattern observed in the Chinese and Japanese populations [7,8,11]. The difference in the sagittal plane screw angulation when compared with other ethnic groups confirms that the patient's ethnicity has an impact on the screw trajectory, as previously demonstrated by studies [12].

With regard to the transverse angulation of the S2AI screw trajectory, the study by Yamada et al. [11] in the Japanese population (right 37.7°±7.5°/left 37.9°±7° in males and right 32.4°±7.1°/left 32.8°±7.6° in females) and Li et al. [7] in the Chinese population (right 38.4°±5.3°/left 37.8°±4.7° in males and right 34.4°±5.1°/left 34.1°±5.9° in females) demonstrated that males had significantly higher transverse angulation than females, although another study by Zhu et al. [8] in the Chinese population (right 37.16°±3.14°/left 36.49°±3.14° in males and right 36.27°±3.27°/left 35.72°±3.76° in females) and by Tavares Junior et al. [10] in the Brazilian population (33.91°±2.20°) demonstrated no significant gender difference regarding S2AI screw transverse angulation. Females had significantly higher transverse angulation than males in our study, which differed from the results of previous studies involving other ethnic groups. Three variables may influence the transverse screw trajectory, according to our research methodology: midline location of the screw entry point, iliac width, and distance of the point along iliac width with reference to the inner iliac cortex depending on the screw diameter. No significant gender difference was observed regarding the midline distance of the screw entry point, and in almost all of our study populations, the 8.5-mm screw diameter was selected irrespective of the gender, negating their influence on the transverse screw trajectory. Since females had a significantly narrower iliac width than males, the transverse screw trajectory passed more laterally in females than in males at the level of the iliac width, explaining the pattern observed in our study.

Prior studies have recommended that the distance between the screw trajectory and the greater sciatic notch along the sagittal plane be kept below 20 mm, resulting in primarily cortical bony purchase for the S2AI screw and increased stability [23]. Our study results regarding sciatic notch distance were as per prior recommendations, and no significant gender difference was observed, which was similar to the study results obtained by Liu et al. [14] (right 16.23±2.75 mm/left 15.78±3.46 mm in males and right 17.16±2.87 mm/left 16.77±2.94 mm in females) in the Chinese population. Females had significantly greater screw depth from the skin than males in the S2AI screw skin distance, which is contrary to previously published studies for different ethnic populations [8,10]. The explanation may be in accordance with the reason put forward by prior studies, which we also believe, that lumbopelvic patterns vary according to race, sex, skeletal maturity, and age, resulting in the differences for the S2AI screw morphometric parameters [12]. The current research has some limitations. Since the reference lines for assessing anatomical parameters were subjectively established, our measurements may have contained some error. The present study population included those with relatively healthy spine without any pelvic deformity, whereas spinopelvic fixation is usually performed in patients with major spinal deformities, including the pelvic region, which results in the inability of data usage in guiding S2 AI screw insertion in such patients. In the present study, the 8.5-mm screw diameter was the maximum, which we considered for anatomical measurements. If a screw diameter >8.5 mm is considered, the morphometric measurements regarding the S2AI screw may vary. We did not investigate the impact of the spinopelvic parameters on the S2AI screw measurements, as suggested by a recent study by Vivace et al. [24], which found an inverse relationship between the pelvic tilt and cephalocaudal S2AI screw trajectory. The present study population included those primarily from northern India, which may not represent the full spectrum of India's ethnic diversity. Despite these limitations, this is the first CT-based morphometric study in the Indian population using the "safe trajectory method" for S2AI screws.

Conclusions

To the best of our knowledge, this is the first CT-based study of S2AI screw morphometric parameters using the "safe trajectory method," which is only available in the Indian population. Based on our methodology, we discovered that the S2AI screw trajectory is significantly more caudal and lateral in females than in males, that the maximum screw length is sufficient for use in clinical practice regardless of gender, and that 8.5 mm or even larger screw diameters are feasible in the majority of the Indian population. Additional multicentric studies of S2AI screw insertion in the Indian population, including clinically based studies, may help consolidate and expand the morphometric data obtained in this study.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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