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ORIGINAL ARTICLE

Software-assisted preoperative planning of S1 Alar Iliac screws: a 3D morphometric and anatomical study

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Abstract

Purpose S1 alar iliac (S1AI) trajectory has gained popularity as a salvage technique for revision surgeries and failed constructs in the lumbopelvic region. This study aims to investigate the morphometry of this new trajectory based on 3D models. The possible role of gender, ethnicity and view angle (surgeon's vs. radiologist's) was investigated.

Methods Computed tomography-driven virtual 3D models of spinopelvic region were created applying Materialize MIMICS software, and assessed for coronal and sagittal radiographic versus surgeon's view angles, and morphometry of the screw trajectory. Independent-samples *t* test was used to analyze the results. *P* value was set at $<=0.05$. The Statistical Package for the Social Sciences Software (SPSS version 24.0) was used for the statistical analysis.

Results A total of 164 3D models were simulated with a total 328 screws inserted satisfactorily within the S1AI trajectory. S1AI instrumentation was feasible in 96.48%. The mean radiological coronal angle was $50.619' \pm 8.590'$ and the mean coronal angle for surgeons' perspective was $10.263' \pm 5.860'$. The mean radiological and surgeon's perspective sagittal angles were found to be $44.532' \pm 6.424'$ and $31.164' \pm 5.455'$, respectively. A statistically significant difference was found between anatomical and surgeon's perspective trajectories. Neither the pelvic laterality nor the gender influence the screw angles, length and diameter in radiological versus surgeon's view angles.

Conclusion Preoperative 3D modeling would be an invaluable adjunct to increase the accuracy of S1AI screw placement. Surgeon's perspective of the trajectory differs from standard CT sections and should be considered in preoperative planning.

Keywords Anatomical · Lumbopelvic fusion · Morphometric · S1 alar iliac · S1AI

Introduction

Spinopelvic fusion has enabled spine surgeons to fix long constructs down to the pelvis. There is now a general consensus that spinopelvic fusion should be attempted to prevent pseudarthrosis leading to hardware failure in cases of deformity, three-column lumbar osteotomies, tumors involving the sacrum, high-grade L5/S1 spondylolisthesis and adult degenerative scoliosis.

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Over the past four decades, the surgical technique for the spinopelvic fusion has been changed dramatically to not only improve the biomechanical stability of the construct, but also to decrease postoperative morbidity. The Galveston technique used contoured rods for pelvic fixation and was first introduced by Allen& Fergussen in 1984 [1]; however, the unacceptable high rate of rod fracture of this pioneer technique led to the introduction of iliac bolt screws with the application of offset connectors to connect spinal screws to pelvic screws [2]. A modified technique for iliac bolt screw insertion was later advocated to decrease soft tissue complications associated with the prominancy of traditional iliac bolts [3]. Over the last decade, the introduction of S2 alar iliac (S2AI) screws and its reported favorable outcome has made the use of S2AI screws as the standard technique for spinopelvic fusion [4, 5].

In recent years, S1 alar iliac (S1AI) fixation has been introduced as an innovative technique by some authors [6]. In comparison with the older S2AI technique, the benefits of the S1AI trajectory may include a smaller skin incision, lower chances of infection, less soft tissue dissection and surgeons' familiarity with the L5/S1 anatomy [7]. Although the technique sounds to be intriguing, the current literature lacks sufficient studies comparing the biomechanics of S1AI screws with S2AI or Iliac screws, and to the best of our knowledge, only a few case series and two morphometric studies in the Chinese population have been so far published introducing S1AI trajectory [6–11]. Because of the anatomical variation in sacral and pelvic anatomy, morphological studies comparing the races may elucidate possible ethnic differences, which have surgical importance. The present study aims to determine any morphometric or anatomical differences in the placement of S1AI screws applying simulated 3D models of the lumbopelvic bony structure. It also aims to find whether the surgeon's perspective differs from the radiologist view in terms of the trajectory angles.

Materials and methods

This is a descriptive anatomical and morphological study based on computed tomography-driven virtual 3D models of spinopelvic region to verify the feasibility of the new trajectory of S1AI in the general population. The study was approved by the institutional review board and ethics committee (IR.IAU.PS.REC.1399.066). The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

All the patients aged between 18 and 70 years old, who required abdominopelvic CT scans due to disorders other than spinal problems in one academic center, were recruited in this study from May 2021 to August 2021. All the scans were taken using Siemens multi-detector CT scanner at our institution and the images were taken with the same protocol: electric current of 220 mA, voltage of 120 kV, slice thickness of 1 mm and 512×512 pixels per slice. The patients with lumbopelvic deformities, lower lumbar and pelvic tumors, congenital anomalies, previous lumbosacral surgery, lower lumbar scoliosis, pelvic tilt or asymmetry and patients whose CT scans could not be perfectly simulated due to severe osteoporosis or axial CT cuts with a slice thickness more than 1 mm were excluded. The images were then reviewed on our institutional Picture Archiving and Communication Systems (PACS). The images were exported in Digital Imaging and Communications in Medicine (DICOM) format from our local PACS. The data was finally imported to the Materialize MIMICS software (version 20, Materialise NV, Belgium) for 3D virtual modeling and analysis.

To reconstruct the lumbopelvic 3D models, the threshold value on MIMICS was changed to "bone CT" as "226-Max" and the masked area was cropped to only contain L4 through sacrum and pelvis (Fig. 1). Additionally, two pelvic screws were simulated by MIMICS software, with a radius ranged from 7.0 to 8.5 mm and a length of 75 mm. Each of the screws were then virtually inserted and positioned into one hemipelvis (right vs. left), and were adjusted within the iliac bone in such a way that the screw never penetrate the alar iliac borders when rotating the 3D model in a 360' fashion (Fig. 1). The ideal insertion point was set to be midway

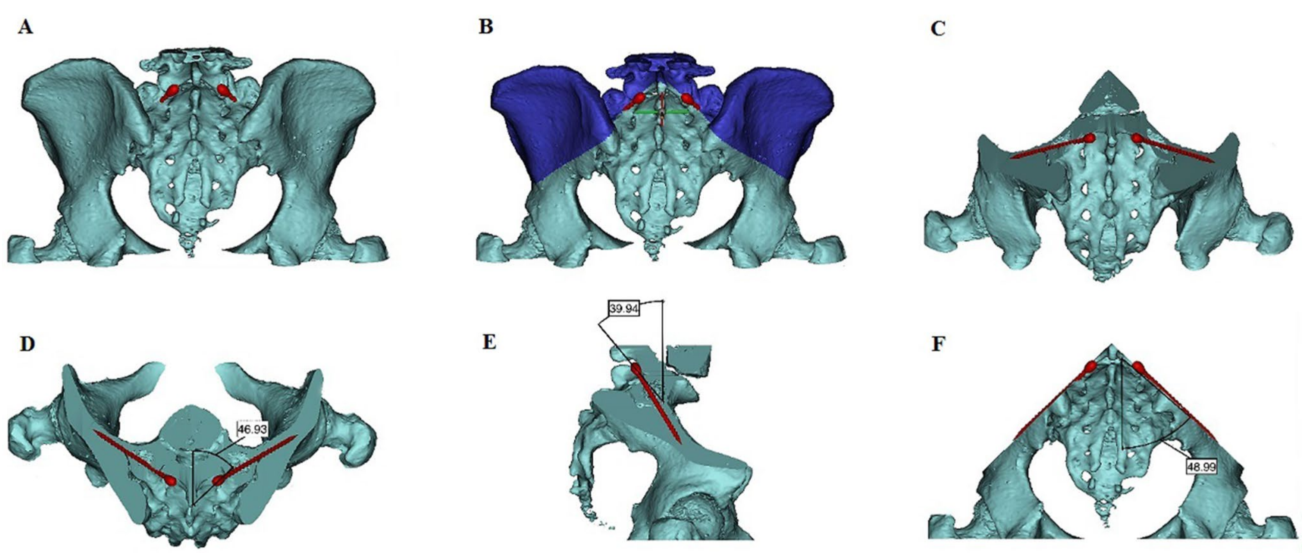

Fig. 1 S1AI trajectory on 3D lumbopelvic models created by MIMICS software. Two screws were inserted within the S1AI trajectory using the anatomical landmarks (**A**). The cut tool on MIMICS was applied to clearly see the trajectory pathway (**B**, **C**). The 3D model was then rotated in a 360' fashion to fine-tune the position of the screw so that not to violate the alar iliac borders. Axial, sagittal and coronal trajectory angles were measured for each screw (**D**, **E**, **F**)

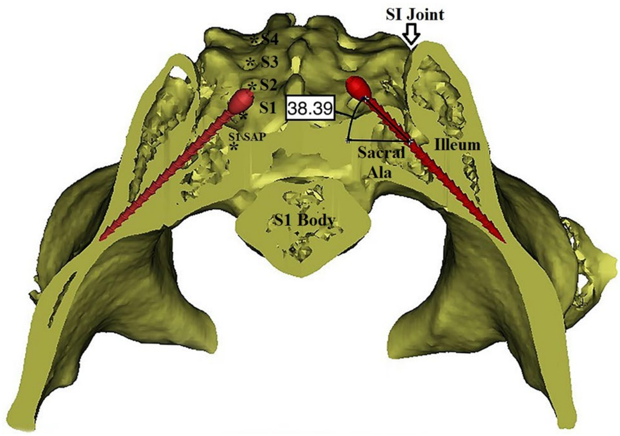

Fig. 2 Anatomical landmarks used for S1AI trajectory on 3D models. S1 through S4 foramen and S1 superior articular process (S1AP) have been shown with*. The insertion point was selected halfway between SAP and S1 foramen on a line connecting the lateral borders of the two mentioned landmarks. The trajectory pathway is toward anterior inferior iliac spine (AIIS) traversing the sacroiliac joint (SIJ)

between the first posterior sacral foramen (s1) and the base of S1 superior articular process (SAP), lateral to the line connecting the two aforementioned anatomical landmarks (Fig. 2). The screws were then double checked in the sagittal and coronal CT sections in order to confirm that they have not perforated either of the iliac cortices (Fig. 3).

The following measurements were calculated for each screw. Å: the coronal radiographic angle of the screw trajectory (Fig. 1F), ß: the sagittal radiographic angle of the screw trajectory (Fig. 1E), L: the maximum possible length of the trajectory, and D: the minimum diameter of ileum on axial cuts. To measure maximum length and minimum diameter, we used the "cut" tool on MIMICS to clearly see the trajectory pathway (Fig. 1). In the cut model, the length was measured using a straight line from the insertion point to the furthest point of screw trajectory without breaking the pelvis walls.

We hypothesized that because of the contralateral position of the surgeon with respect to the surgical trajectory of S1AI screws, and the obliquity of surgeon's point of view as compared to the radiologist point of view, the angles of insertion from surgeon's perspective might

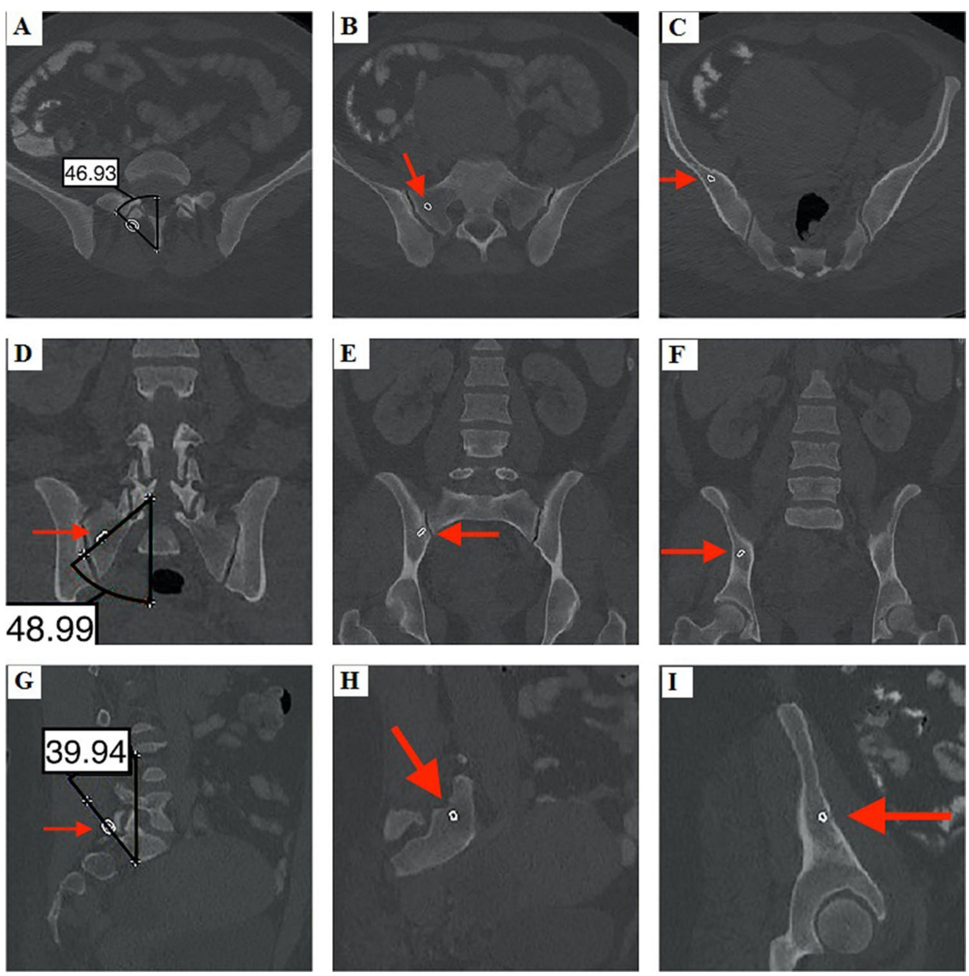

Fig. 3 Reformatted CT scans of the lumbopelvic region were used to track the correct position of the screw with suggested trajectory angles measured by MIMICS software. Axial (**A**, **B**, **C**), coronal (**D**, **E**, **F**) and sagittal (**G**, **H**, **I**) track of the screw

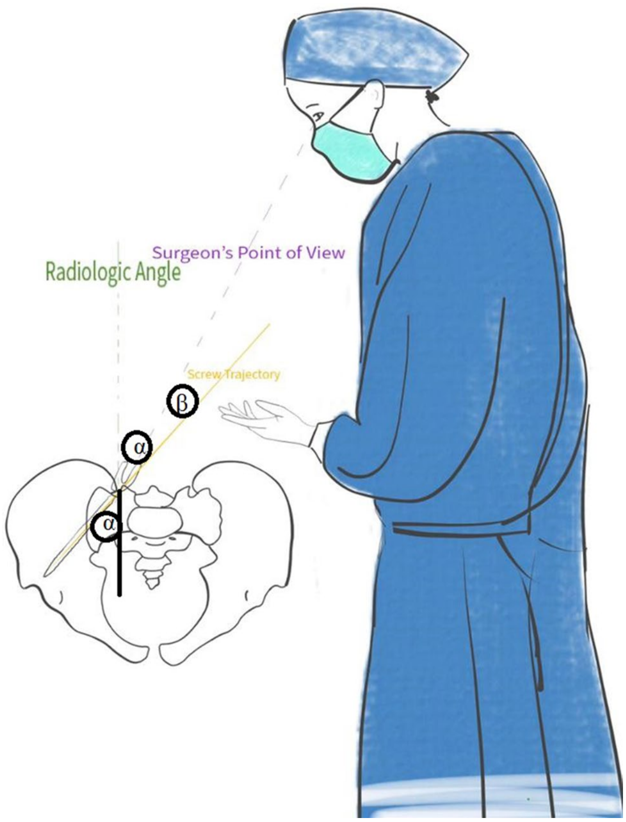

Fig. 4 Schematic drawing comparing the radiologist's versus surgeon's view angles of the S1AI trajectory

be different from radiological angles (Fig. 4). MIMICS employs a trio of guiding axes perpendicular to each other, which can be used to measure XYZ angles in a three-dimensional manner. Therefore, this tool was used in our study to measure the angles from the surgeon's perspective on 3D models, and to homogenize our angle measurement. To include surgeon's point of view in our measurements, the DICOM images were re-sliced in an oblique fashion parallel to the S1AI trajectory by the software. Using "re-slice tool," we re-sliced coronal images with the angle of 45° to compensate the obliquity of the surgeon's perspective with respect to the contralateral hemipelvis. The following two angles were then measured: the coronal angle with respect to surgeon's point of view, and the sagittal angle with respect to surgeon's point of view.

To increase inter- and intra-observer reliability, all the variables were measured twice by two of authors (P.V and G.S) and the mean values were used for further analysis. The results were represented as "mean ± SD." Independent-samples *t* test was used to analyze the results. *P* value was set at $< = 0.05$. Kappa test was used to verify the inter-observer agreement on measurements. The Statistical Package for the Social Sciences Software (SPSS version 24.0) was used for the statistical analysis.

Results

Out of the initially recruited 428 patients, a total number of 87 patients met our inclusion criteria. Eighty-seven CT scans were imported to MIMICS software for simulations. Two of the patients were initially excluded due to the unsatisfactory simulations in MIMICS software (low integrity of simulated pelvis). Of the remaining 85 CT scans, S1AI instrumentation was not feasible in three because of the thin ileum (3.52%). Out of the remaining 82 CT scans, 164 3D models were simulated including both radiological and surgeon's perspective models. This included 328 screws inserted satisfactorily within the S1AI trajectory. Male-to-female ratio was 1.34, including 47 male and 35 female patients. The mean age of patients was 52.67 ± 15.69 years old (range: 18 to 72).

In this study, it was found to be virtually possible to insert S1AI screws within the pelvis in 96.48% of the patients.

Regarding radiological measurements, no statistically significant difference was found in coronal and sagittal angles of screw placement between left and right screws (*$p = 0.816$ and $p = 0.541$*, respectively) (Table 1). Also no such difference was found between male and female in neither of the mentioned variables (*$p = 0.470$* and *$p = 0.157$,* respectively) (Table 1). Same pattern was found when comparing coronal and sagittal trajectory angles in both hemipelvis (Coronal: $p = 0.458$ and Sagittal $p = 0.432$) and the two genders (Coronal: $p = 0.205$ and Sagittal $p = 0.157$) measured from surgeon's point of view (Table 1).

The mean radiological coronal angle was 50.619' ± 8.590' and the mean coronal angle for surgeons' perspective was 10.263' ± 5.860'. The mean radiological and surgeon's perspective sagittal angles were found to be 44.532' ± 6.424' and 31.164' ± 5.455', respectively (Table 2).

The coronal and sagittal angles exhibit a statistically significant difference when compared between anatomical and surgeon's perspective trajectories. ($p = 0.000$ and $p = 0.000$) (Table 2).

The mean screw length for men and women was 104.676 ± 7.473 mm and 102.929 ± 8.762 mm, respectively, which showed no statistical significance (*$p = 0.262$*). (Table 1).

The mean screw diameter showed no significant statistical difference between male (12.234 ± 2.054 mm) and female (12.123 ± 1.781 mm) patients (*$p = 0.765$*) (Table 1).

In total, the mean screw length was 104.896 ± 7.455 and 102.931 ± 8.596 mm, and the mean screw diameter was 12.486 ± 1.669 and 11.886 ± 2.137 mm in left and right hemi-pelvises, respectively (Table 1). Pelvic laterality

Table 1 S1AI trajectory angles and screw characteristics

		P value
Coronal angle		
Radiological view		
Left	50.811' ± 9.663'	0.816
Right	50.426' ± 7.451'	
Male	50.095' ± 9.606'	0.470
Female	51.295' ± 7.109'	
Surgeon's view		
Left	9.116' ± 3.720'	0.458
Right	10.171' ± 5.818'	
Male	11.129' ± 6.787'	0.205
Female	9.116' ± 3.720'	
Sagittal angle		
Radiological view		
Left	44.155' ± 7.468'	0.541
Right	44.909' ± 5.219'	
Male	43.768' ± 7.182′	0.157
Female	45.519' ± 5.194'	
Surgeon's view		
Left	30.366' ± 5.850'	0.432
Right	31.747' ± 6.204'	
Male	31.156 ± 4.887	0.157
Female	31.173' ± 6.110'	
Maximum screw length (mm)		
Left	104.896 ± 7.455	0.203
Right	102.931 ± 8.596	
Male	104.676 ± 7.473	0.262
Female	102.929 ± 8.762	
Maximum screw diameter (mm)		
Left	12.486 ± 1.669	0.104
Right	11.886 ± 2.137	
Male	12.235 ± 2.054	0.765
Female	12.123 ± 1.781	

Table 2 Dramatic significance was observed between the radiological and surgeon's views of coronal and sagittal angles for S1AI trajectory

	Coronal angle (Mean ± SD)	*P* value	Sagittal angle (Mean ± SD)	*P* value
Radiological view	50.619' ± 8.590'	0.000	44.532 ± 6.424	0.000
Surgeon's view	10.263' ± 5.860'		31.164 ± 5.455	

(right vs. left) showed no statistical significance regarding the length and diameter of selected screws (*p = 0.203* and *p = 0.104*).

Discussion

The results of the present study confirm that software-assisted preoperative measurements of S1AI trajectory might be an invaluable adjunct in accurate preoperative planning for spinopelvic fixation. We also found that the coronal trajectory of S1AI screws may vary by ethnic factors. Furthermore, surgeon's perspective of the trajectory differs from radiological measurements and should be considered in real-life surgeries.

S1AI trajectory has been recently added to the surgeon's armamentarium in long segment spinal fusions extending to the pelvis [6, 9]. This can be a tricky area for instrumentation for every spine surgeon, as S1 and S2 dysmorphism has been reported to be present in up to 44% of the general population [12]. The literature includes very few studies considering the biomechanical and clinical advantages of S1AI screw trajectory in comparison with S2AI and iliac screw fixation methods [6, 8, 9]. The novelty of this surgical method, and the unfamiliarity of spinal surgeons with S1AI trajectory, would be the explaining reason for such paucity of the extant literature.

Preoperative planning is of outmost importance to achieve favorable postoperative outcome in spine surgery [13]. Complex spine surgery mandates measuring important instrumentation parameters, such as trajectory angles based on the preoperative reconstructed CT scans. In recent years, the use of computer software like Surgimap (Nemaris Inc., New York, NY, USA) or MIMICS has enabled spine surgeons to virtually simulate postoperative images as well as planning a tailored surgical approach, especially for deformity cases [14, 15]. Thanks to the modern technological advancements, the current application of O-arm and navigation has also helped the spine surgeons to insert spinal instruments with minimal errors; however, these costly facilities are only available in few spine centers. As the trajectory of S1AI screws is contralateral to the surgeon and proceeds in a downward and lateral direction from the very narrow portions of the iliac bone toward the anterior inferior iliac spine, the spatial recognition of the regional anatomy is crucial for a safe and proper insertion of the screws. The results of our study suggest that the use of software like MIMICS may help surgeons in centers with limited intra-operative imaging resources, to use software-assisted preoperative planning and the free hand technique for sacral iliac screw placement.

Wu et al. performed a comparative virtual study on S1AI through S4AI screws in a Chinese population [10]. They found the feasibility of S1AI to be 100%, which is consistent with the findings of our study (96.48%). In this study, the authors found that the S1AI screws can be safely inserted in a wide range of coronal (39' to 54') and sagittal (30' to 44') angles by tilting the screw trajectory in upward and downward directions within the pelvis. The maximum upward trajectory angle was 43.6' ± 5.44' and 43.7' ± 5.22' in right and left sides, respectively, which correlates only with sagittal radiological angle in our study (right: 44.909' ± 5.21', left: 44.155' ± 7.46'). They also found the mean S1AI screw length to be 102.1 mm and 103.3 mm in right and left sides, respectively, which is consistent with the length of screws in our study (right: 102.93 mm and left: 104.89 mm). When compared to the data presented in Wu et al. [10] study, the findings of the present study on patients with Middle Eastern background may imply the possible role of ethnic factors in the coronal trajectory of S1AI screws. This difference may be due to the variation in pelvic width between the two races.

Wang et al. did another 3D imaging study of S1AI trajectory in Chinese population in 2018 [11]. The authors have reported the maximum length of S1AI screw to be 120.06 ± 4.21 mm (range, 113.9–129.1 mm) in males and 112.47 ± 6.11 mm (range, 102.2–125.6 mm) in females. They also have found a statistically significant difference in sagittal angle of the screw between male and female population. This may indicate the possible role of gender on the parameters of S1AI trajectory; however, our study showed no significant difference regarding the sagittal or coronal angles between the two genders. Nevertheless, this finding also highlights the importance of software-assisted preoperative planning to individualize every patient for the surgery.

In the present study, a statistically significant difference was found between the radiological sagittal and coronal angles and the corresponding angles from the surgeon's perspective. While the mean value of the radiological coronal and sagittal angles was found to be 50.619' ± 8.590' and 44.532' ± 6.424', respectively, these angles were measured to be 10.263' ± 5.860' (coronal) and 31.164' ± 5.455' (sagittal) from the surgeon's point of view. We believe this difference is because the screws are inserted from the contralateral side by the surgeon, which is a different perspective than the ipsilateral radiological angles. As can be seen in Fig. 4, both the radiologist and the surgeon make their view angle with respect to the standard screw trajectory extending between the insertion point and the anterior inferior iliac spine (AIIS). While the surgeon's perspective is contralateral and oblique to the insertion point, the radiological view angle is ipsilateral and vertical to this point. Hence, the radiologist view angle (α) is measured greater than the surgeon's (β). Measuring the angles from the surgeon's perspective introduced in our study is a novel way for preoperative planning in spine surgery, especially in procedures when screws are inserted from the contralateral side by the surgeon. Despite the additional time this method might take to re-slice the images and measure the angles and values from the surgeon's point of view, it might decrease the possible errors in screw placement by simulating a real-life surgery.

The present study has some shortcomings. First, this study was performed on healthy lumbopelvic CT scans, excluding patients with deformity and prior history of lumbosacral surgery. Considering the fact that the measured indices and angles might be different in patients with spinal deformity or pelvic obliquity, the results of our study might not be applicable to these patients. Second, in a large cohort of patients the possibility of individual anatomical variations should be carefully sought to minimize any errors in screw placement. Third, the low sample volume may preclude us from determining a firm conclusion on ethnic and gender variations. Fourth, preoperative planning and measurements were done on CT scans in supine position. Intra-operative prone positioning of the patient with gelatin pads under the iliac crest may change the sacral slope and especially the predicted sagittal angle, which should be considered in real-life surgery.

Future directions would be to compare the accuracy of screw placement with software-assisted preoperative planning and screw placement with free hand technique, intra-operative O-arm, navigation and robotics. Also issues like operative time, surgical costs, infection rate and radiation exposure both to the patient and operating room staff would be of outmost importance.

Conclusion

From the anatomical perspective, S1AI screw placement is feasible in 96.48% of patients. Variations in pelvic anatomy between the genders and races may imply differences in sagittal or coronal insertion angles between current studies. Software-assisted preoperative planning for S1AI trajectory screws and 3D modeling could increase the accuracy of screw placement compared to preoperative CT scan, alone. Surgeon's perspective of the trajectory differs in sagittal and coronal planes from standard CT sections and should be considered in preoperative planning.

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Declarations

Conflict of Interest The authors declare no conflict of interest.

Ethical approval Approval was obtained from the ethics committee of Islamic Azad University of Medical Sciences (IR.IAU.PS.REC1399.066). The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

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