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*Original Article*

# Safe regulable angle and optimum trajectory of the second sacral alar iliac screw: a digital simulation study

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**Abstract:** Objectives: The posterior second sacral alar iliac (S2AI) screw fixation technique has a wide range of clinical applications. The optimum trajectory of S2AI screws has been reported by numerous studies. However, morphological and anatomical structures of the safe range of the S2AI screw fixation technique have rarely been studied. Methods: Three-dimensional reconstruction was performed on computed tomography (CT) data of 40 adult pelvises without relative lesions. One cylinder (diameter of 7.0 mm) was drawn to imitate the S2AI screw and CT imaging planes were rotated until they matched the ideal S2AI trajectory. Parameters of S2AI screw trajectory measurements and the safe regulable angle were recorded. Results: Inward, outward, upward, and downward safe regulable angles, as well as TSV and SAG angles on the left side of females, were 4.7 ± 0.6°, 6.7 ± 0.4°, 8.1 ± 0.7°, 6.9 ± 0.6°, 11.5 ± 1.2°, and 15.5 ± 2.2°, respectively. Angles of the males and the right side of females were in accord with angles of the left side of females. Conclusion: This study recommends insertion of S2AI screws with approximately a 28° SAG angle in the sagittal plane (5° more for females) and a 34° TSV angle in the transverse plane (3° more for males). Insertion of the S2AI screws could be relatively close to the upward and outward sides, based on the optimum trajectory, because of less safe regulable angles at inward and downward sides.

**Keywords:** Safe regulable angle, insertion trajectory, sacral alar iliac screw, digital simulation

## Introduction

After Sponseller and Kebaish devised the posterior second sacral alar iliac (S2AI) screw fixation technique in 2007 [1, 2], it has been widely applied for surgical treatment of pelvic obliquity, high-grade spondylolisthesis, lumbopelvic trauma, long spinal fusions, and other spinal deformities [3]. The S2AI screw fixation technique has merits, compared to other methods of spinopelvic fixation, including the traditional iliac screw. The S2AI screw fixation technique has more fixed segments and stable biomechanical torsion because both the ilium and the sacrum are anchored [4]. Compared to traditional iliac screw fixation, the direction and length of S2AI screws could facilitate more reliable stability [5-8]. Since minimally disturbed soft tissue completely covers the implants, the S2AI screw technique may minimize blood loss and infection rates [4, 9-11]. In contrast, the traditional iliac screw technique needs extensive surgical exposure of the posterior superior iliac spine (PSIS). This could lead to minimal soft tissue coverage and contribute to a higher risk of bleeding and infection rates, reportedly as high as 4% [12]. Hence, the S2AI screw has been identified as a replacement for the iliac screw, due to those unfavorable factors [2].

The S2AI screw can be inserted using the percutaneous technique [2, 11]. However, there are no relatively uniform entry points of the S2AI screw optimal trajectory. Chang TL et al. confirmed that the entry point of screws was selected as 1 mm inferior and 1 mm lateral to the S1 dorsal foramen [1]. Ai-Min Wu et al. determined the screw entry point as the cross point of the midline between the upper and lower dorsal sacral foramina and the line of the inner fovea of the transverse process of the sacrum [13]. In this study, entry points of S2AI screws were chosen at the cross point of the lateral sacral crest and the midline between the S1 and S2 dorsal foramen, based on reliable and reproducible results of previous studies.

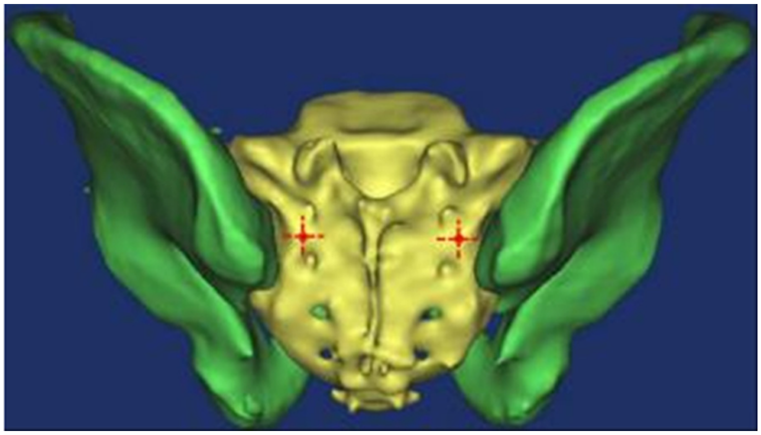


**Figure 1.** Entry points (red point) of S2AI screws were chosen at the cross point of the lateral sacral crest and the midline between the S1 and S2 dorsal foramen in a three-dimensional pelvic reconstruction model.

S2AI screws traverse the sacroiliac joint and terminate in the ilium above the sciatic notch [1, 3, 4, 6, 14-18].

Typically, intraoperative fluoroscopy has been used to assess S2AI screw insertion, but most of the C-arm machines provide two-dimensional images only. If a screw is very close to the surface of the inner and outer cortices of the sacral ala on lateral and frontal radiographs, it may have actually perforated the bone cortex, although it is still seen in the sacral ala in the radiographs. The presence of contrast, intestinal gas, and increased soft tissue density, due to obesity, can make it difficult to obtain and interpret appropriate intraoperative fluoroscopic images. These negative factors for S2AI screws also add to the insertion difficulty. Malpositioned implants and excessive deflection of the S2AI screw could increase the risk of puncturing the sacral or iliac cortex, damaging tissues proximal to the pelvis, such as the sciatic nerve, superior and inferior gluteal artery, veins and nerves, and other neurovascular tissues [19]. These factors could have catastrophic consequences [20-22].

Very few studies have reported the morphological and anatomical structures for the safe range of the S2AI screw fixation technique, along with screw insertion in many lumbosacral-pelvic disorders. The current study attempted to calculate safe regulable angles in four directions and the optimum trajectory of S2AI screws through digital simulation, thereby identifying the presence of a stereoscopic safe range of S2AI screws. The aim is to help clinicians better understand the S2AI screw fixation technique and reduce risks of perforation of the cortex.

## Materials and methods

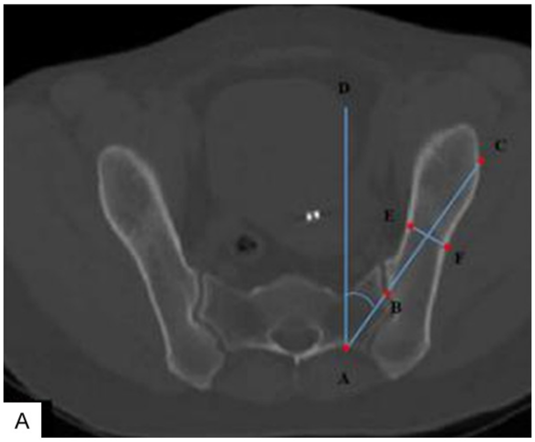
This study was a retrospective analysis of a case series. Analyzing the radiographic data of patients, the current study excluded congenital bone disease, history of trauma, pelvic fractures, and instrumentation surgeries. Integrity assessment and quality control of computed tomography (CT) data were routinely implemented before data processing. The study population consisted of 40 patients (20 males and 20 females), with a mean age of 34.2 years (range 18-57 years). Mean height of males and females was 171.68 ± 2.88 cm and 154.35 ± 4.67 cm, respectively. Mean weight of males was 62.57 ± 4.80 kg, while that of females was 55.35 ± 6.83 kg. DICOM image data of 40 adults were obtained by CT scanning the pelvic regions using a tube voltage of 120 kV, tube current of 200 mA, slice thickness of 1 mm, and interlayer spacing of 0.5 mm. For data consistency, the same investigator, familiar with the anatomy of the pelvis, measured all parameters and recorded the average value of measurement results. Experiments were repeated three times. The following steps were used for data analysis from each case.

### *Model construction*

CT images were transformed into a three-dimensional (3D) pelvic reconstruction model via the interactive medical imaging control system Mimics 17.0 (Materialise, Leuven, Belgium). After 3D digital images were calculated and reconstructed, a cylinder (diameter of 7.0 mm) was drawn to imitate the S2AI screw [23].

### *Determination of the entry point*

Entry points of S2AI screws were chosen at the cross point of the lateral sacral crest and midline between the S1 and S2 dorsal foramen into a 3D pelvic reconstruction model (**Figure 1**).



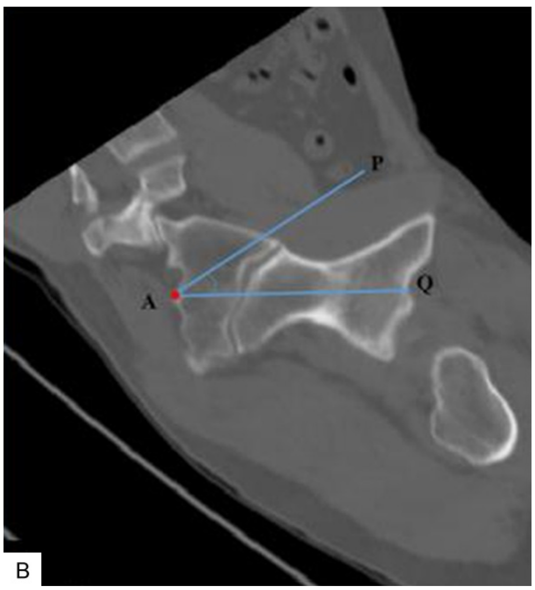




**Figure 2.** Optimum trajectory measurements of transverse and sagittal plane images along S2AI trajectory. TSV angle (∠DAC), iliac width (Line EF), maximal length (Line AC), and sacral distance (Line AB) in transverse plane along S2AI trajectory (A). SAG angle (∠PAQ) in sagittal plane along S2AI trajectory (B). The data of a patient (female, 28 years) on the left side; ∠DAC = 35.72°; line EF = 14.88 mm; line AC = 114.98; line AB = 25.31 mm; ∠PAQ = 34.20°.

*Image plane adjustment*

The entry point was specified for use at the center of rotation. CT imaging planes were rotated until they matched the ideal S2AI trajectory (greatest length and width of osseous channel) of the pelvis.

*Parameter measurements*

Optimum trajectory of S2AI screws: TSV angle is defined as lateral trajectory angulation in the transverse plane (**Figure 2A**, ∠DAC). SAG angle is defined as caudal trajectory angulation in the sagittal plane (**Figure 2B**, ∠PAQ). Max-length is defined as the maximal distance from the entry point to the anterior inferior iliac spine based on the optimum trajectory (**Figure 2A**, Line AC). Iliac width is defined as the narrowest iliac width measured between the outside cortices in the transverse plane (**Figure 2A**, Line EF).

Safe regulable angle of S2AI screw: As shown in **Figure 3A**, on the transverse plane, the axis of the optimal entry screw was crossed with the ilium cortex at A (the entry point). Point E, F' (the narrowest spots of two margins) was used to make parallel lines (Line KG and Line IH) of the axis of optimum trajectory (Line AC), which pierced the vertebral body at points K and I. Through point I (the nearest entry point) and point A (the entry point) to make vertical lines (JI and GH), researchers formed the rectangular IJGH (the safe area of S2AI screws) and the rectangular LMNO (the ichnography of S2AI screw simulation). ∠JML and ∠INO were the safe regulable inward and outward angles of the screw transverse plane, respectively. As shown in Figure 3B, the quantitative measurement method of the safe area and safety adjustment on the sagittal plane was the same as on the transverse plane. Lastly, ∠UM'L' and ∠TN'O' are defined as upward and downward safe regulable angles, respectively.

*Statistical analysis*

Statistical analysis was performed using SPSS statistical software program 22.0. Independent-samples t-test was used to detect differences in gender and limb side of sacroiliac joints. For all statistical tests, $P < 0.05$ indicates significance.

## Results

Safe regulable angles in four directions and the optimum trajectory of S2AI screws were calculated in all 40 pelvises through digital simulation. **Table 1** shows the mean value and standard deviation (SD) for the angulations and lengths of optimal SAIS trajectories. In the sagittal plane, the SAG angle of females (left: 33.9 ± 6.5°; right: 34.8 ± 7.1°) was larger than that in males (left: 28.3 ± 7.7°; right: 29.0 ± 7.4°) (P = 0.02). In the transverse plane, the TSV angle of females (left: 34.1 ± 5.9°; right: 34.4 ± 5.1°)

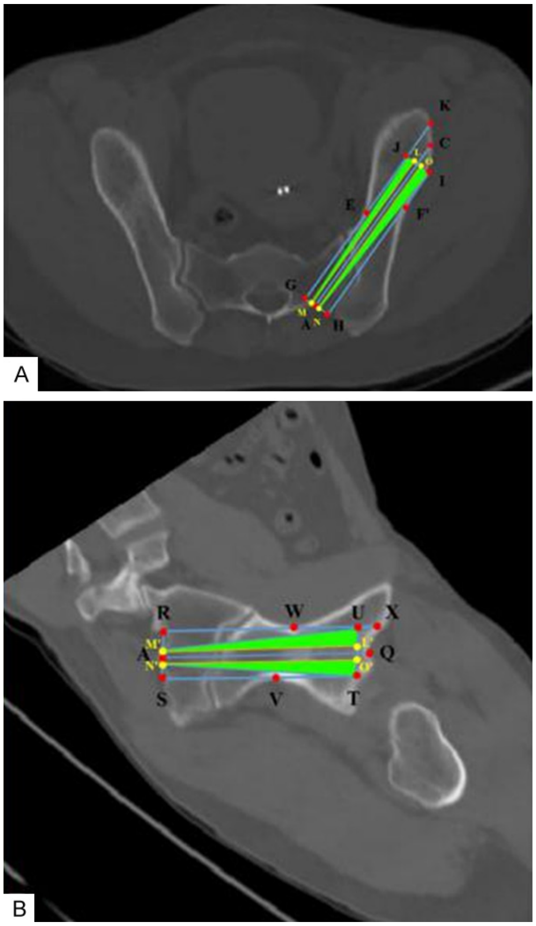



**Figure 3.** Safe regulable angles of S2AI screws in transverse and sagittal planes along the S2AI trajectory. The inward (∠JML) and outward (∠INO) safe regulable angles in transverse plane (A). The upward (∠UM'L') and downward (∠TN'O') safe regulable angles in sagittal plane (B). The TSV safe regulable angle was defined as the sum of inward and outward safe regulable angles in the transverse plane. Similarly, the SAG safe regulable angle was defined as the sum of upward and downward safe regulable angles in the sagittal plane. The safe angle data of a patient (female, 28 years) on the left side; ∠JML = 4.55°; ∠INO = 6.18°; ∠UM'L' = 8.00°; ∠TN'O' = 6.94°; TSV safe regulable angle = 10.73°; SAG safe regulable angle = 14.94°.

was significantly smaller than that in males (left: 37.8 ± 4.7°; right: 38.4 ± 5.3°) (P = 0.03 and P = 0.02, respectively). Compared to females, trajectories of the males were significantly longer, with a max-length of 121.4 ± 9.3 mm (P = 0.02) on the left side and 121.2 ± 8.8 mm (P = 0.02) on the right side. The iliac width of males (left: 17.5 ± 3.4 mm; right: 17.8 ± 3.3 mm) was larger than that in females (left: 15.3 ± 2.6 mm; right: 15.5 ± 2.9 mm) (P = 0.02).

**Tables 2** and **3** show the results of safe regulable angles. There were no significant differences in gender and limb side of sacroiliac joints (P > 0.05). The TSV safe regulable angle is defined as the sum of inward and outward safe regulable angles in the transverse plane. Similarly, the SAG safe regulable angle is defined as the sum of upward and downward safe regulable angles in the sagittal plane. Inward, outward, upward, downward, TSV, and SAG safe regulable angles on the left side of females were 4.7 ± 0.6°, 6.7 ± 0.4°, 8.1 ± 0.7°, 6.9 ± 0.6°, 11.5 ± 1.2°, and 15.5 ± 2.2°, respectively. Angles of males and the right side of females were in accord with results of the left side of females.

## Discussion

Despite significant advances and developments in spinal instrumentation techniques, sacropelvic fixation remains a surgical challenge, especially in neuromuscular scoliosis and severe adult scoliosis [24]. Poor bone quality of the sacrum, complex anatomy, and tremendous biomechanical forces at the lumbosacral junction contribute to the high rates of instrumentation-related problems [9, 15, 25-27]. S2AI screws could provide immediate stability and adequate biomechanical strength of constructs, based on discriminative features wherein both the ilium and the sacrum are anchored based on the direction and length of the screws. In addition, it could correct pelvic obliquity with lower implant profiles, with less soft tissue dissection, shorter operation times, and fewer complications [28, 29]. In recent years, the S2AI screw fixation technique has been widely applied for surgical treatment of lumbosacral-pelvic reconstruction and other disorders.

A previous study in a Chinese population recommended average SAG and TSV angles of S2AI screw insertion of 30-40°, while the average max-length was about 120 mm for males and 115 mm for females. The currents study recommends insertion of S2AI screws with a SAG angle of approximately 28° and a TSV angle of approximately 34°. The SAG angle of females should be approximately 5° more than males, consistent with previous studies [17]. The TSV angle of females should be about 3° less than males, based on current results. This

**Table 1.** Parameters of S2AI screw trajectory measurements (Mean ± standard deviation)

| Parameters | Females | | | Males | | |
|---|---|---|---|---|---|---|
| | Left | Right | P | Left | Right | P |
| Sag angle (°) | 33.9 ± 6.5 | 34.8 ± 7.1 | 0.68 | 28.3 ± 7.7 | 29.0 ± 7.4 | 0.77 |
| Tsv angle (°) | 34.1 ± 5.9 | 34.4 ± 5.1 | 0.86 | 37.8 ± 4.7 | 38.4 ± 5.3 | 0.71 |
| Max-length (mm) | 114.3 ± 9.5 | 114.2 ± 8.7 | 0.97 | 121.4 ± 9.3 | 121.2 ± 8.8 | 0.94 |
| Iliac width (mm) | 15.3 ± 2.6 | 15.5 ± 2.9 | 0.82 | 17.5 ± 3.4 | 17.8 ± 3.3 | 0.78 |
| Sacral distance (mm) | 24.7 ± 2.8 | 24.9 ± 2.5 | 0.81 | 24.4 ± 2.5 | 25.1 ± 2.2 | 0.35 |

For all statistical tests, the *P* value of less than 0.05 indicates statistical significance.

**Table 2.** The safe reguable angle of S2AI screws about the limb side of sacroiliac joint (Mean ± standard deviation)

| Parameters | Females | | | Males | | |
|---|---|---|---|---|---|---|
| | Left | Right | P | Left | Right | P |
| ISRA | 4.7 ± 0.6 | 4.6 ± 0.2 | 0.48 | 4.6 ± 0.3 | 4.5 ± 0.2 | 0.22 |
| OSRA | 6.7 ± 0.4 | 6.5 ± 0.9 | 0.37 | 6.5 ± 0.7 | 6.8 ± 0.5 | 0.12 |
| TSRA | 11.5 ± 1.2 | 11.3 ± 1.5 | 0.64 | 11.2 ± 0.8 | 11.0 ± 1.1 | 0.51 |
| USRA | 8.1 ± 0.7 | 8.3 ± 1.0 | 0.47 | 8.3 ± 0.3 | 8.4 ± 0.5 | 0.45 |
| DSRA | 6.9 ± 0.6 | 6.8 ± 0.9 | 0.68 | 6.7 ± 1.0 | 6.6 ± 0.3 | 0.67 |
| SSRA | 15.5 ± 2.2 | 15.0 ± 1.3 | 0.39 | 15.0 ± 1.5 | 15.3 ± 0.9 | 0.45 |

For all statistical tests, the *P* value of less than 0.05 indicates statistical significance. ISRA: the inward safe reguable angle; OSRA: the outward safe reguable angle; USRA: the upward safe reguable angle; DSRA: the downward safe reguable angle; TSRA: the TSV safe reguable angle; SSRA: the SAG safe reguable angle.

**Table 3.** The safe reguable angle of S2AI screws about the sexuality (Mean ± standard deviation)

| Parameters | Left | | | Right | | |
|---|---|---|---|---|---|---|
| | Females | Males | P | Females | Males | P |
| ISRA | 4.7 ± 0.6 | 4.6 ± 0.3 | 0.51 | 4.6 ± 0.2 | 4.5 ± 0.2 | 0.12 |
| OSRA | 6.7 ± 0.4 | 6.5 ± 0.7 | 0.27 | 6.5 ± 0.9 | 6.8 ± 0.5 | 0.20 |
| TSRA | 11.5 ± 1.2 | 11.2 ± 0.8 | 0.36 | 11.3 ± 1.5 | 11.0 ± 1.1 | 0.48 |
| USRA | 8.1 ± 0.7 | 8.3 ± 0.3 | 0.25 | 8.3 ± 1.0 | 8.4 ± 0.5 | 0.69 |
| DSRA | 6.9 ± 0.6 | 6.7 ± 1.0 | 0.45 | 6.8 ± 0.9 | 6.6 ± 0.3 | 0.35 |
| SSRA | 15.5 ± 2.2 | 15.0 ± 1.5 | 0.41 | 15.0 ± 1.3 | 15.3 ± 0.9 | 0.40 |

For all statistical tests, the *P* value of less than 0.05 indicates statistical significance. ISRA: the inward safe reguable angle; OSRA: the outward safe reguable angle; USRA: the upward safe reguable angle; DSRA: the downward safe reguable angle; TSRA: the TSV safe reguable angle; SSRA: the SAG safe reguable angle.

study recommends S2AI screws with the max-length of female 114 mm/male 121 mm, consistent with the findings of Kwan et al. [29]. This means that the max-length of ideal S2AI trajectory surpasses the length usually used in practice, which is 80 mm [30]. Except for the insertion angle of S2AI screws, iliac width is a key indicator to decide whether S2AI screws successfully traverse the ideal iliac plane. Due to the complex anatomy of the pelvis, iliac width of iliac bones is a variable parameter. In the present study, iliac width of the determined transverse plane was L15.3 ± 2.6 mm/R15.5 ± 2.9 mm in females and L17.5 ± 3.4 mm/R17.8 ± 3.3 mm in males. F. Zhu et al. examined the optimal trajectory and insertion accuracy of S2AI screws, in which the parameter of iliac width was included [17]. Their results of iliac width (L14.76 ± 2.46 mm/R14.94 ± 2.60 mm in females and L16.98 ± 3.52 mm/R17.00 ± 2.81 mm in males) were in accord with present results. Therefore, it is believed that the diameter of the screw will not constitute a limitation if the screw is in the safe regulable angle. This is because the current max-diameter of S2AI screw in clinical practice is 7.5 mm [30]. Thus, the safe regulable angle is critical for insertion of S2AI screws.

The computer simulation showed that the S2AI screw had precise safe regulable angles, except for the optimum trajectory. The current study simulated screws with the optimum trajectory. The diameter (the length of the line OL) of the simulated screw was 7.0 mm. On the transverse plane, it is recommended that the safe regulable angles of females and males are approximately 11.5°. The safe regulable angles of females and males on the sagittal plane are approximately 15.5°. Hence, the TSV angle and SAG angle could be transformed within a certain range. The optimum trajectory is considered as the reference line, which can move about 8.0° upward and 6.5° downward when the entry point and screw angles remain constant on transverse plane. Similarly, it can move about 4.5° and 6.5° inward and outward when the entry point and screw angles remain constant on sagittal plane. Hence, the safe regulable angles of inward and downward sides of the screw are relatively small. It is obvious that, when bigger diameters and longer screws are used, the safe regulable angle will be smaller. In clinical cases, the position is also subjectively determined by surgeons. The angle will slightly differ among different surgeons. Therefore, to avoid penetrating the cortex of the pelvis, this study recommends that the insertion of S2AI screws be relatively close to the upward and outward sides, based on the optimum trajectory. This is due to the relatively less safe regulable angles at inward and downward sides.

The current study had some limitations, however. First, the 3D imaging study did not include clinical cases or cadaveric experiments. Reference lines and data measurement were subjectively established. Second, this study was only based on a Chinese population. Thus, ethnic and gender differences may have impacted the parameters of S2AI screw insertion. Third, present data should be applied to guide S2AI screw insertion in patients without pelvic obliquity or pelvic asymmetry, since all measurements were from normal pelvises without deformities of the skeletal structure. Fourth, if bigger diameter screws are used, the safe regulable angle will be smaller. In practice, there are many diameters of screws available. However, only 7.0 mm screws were used in this study.

## Conclusion

Given the complex anatomy of the pelvis, a S2AI screw could generate an optical illusion of the precise position on intraoperative fluoroscopic radiographs but may have perforated the bone cortex of pedicle. Both optimal trajectories and safe regulable angles are advised to ensure the insertion accuracy of S2AI screws. This study recommends insertion of the S2AI screws with approximately 28° SAG angle in the sagittal plane (5° more for females) and about 34° TSV angle in the transverse plane (3° more for males). In addition, the TSV and SAG safe regulable angles are approximately 11.5° and 15.5°, respectively. It isrecommended that the insertion of the S2AI screws be relatively close to the upward and outward sides, based on the optimum trajectory. This is because of the less safe regulable angles at inward and downward sides. To decrease perforation risks and reduce iatrogenic damage, the current study suggests the generation of a three-dimensional pelvic model for every patient, ensuring the best selection of S2AI screws before surgery and decreasing complications caused by improper screws.

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Project name: Mechanism of ERCC1 gene modifing DNA damage in pressure-induced calcification of intervertebral disc cartilage endplate. Project number: 2018KY813. Project location: China Pinghu Second People's Hospital, 136 East Yashan Road, Zhapu Town, Pinghu City 314201, Zhejiang, China.

## Disclosure of conflict of interest

None.

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