Posterior second sacral alar iliac screw insertion: anatomic study in a Chinese population

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Abstract

Objective To provide radiographic parameters for optimal placement of posterior second sacral alar iliac (S2AI) screw for instrumentation and fusion of scoliosis to the second sacral level in a Chinese population.

Methods S2AI screw trajectories were mapped on three-dimensional computed tomography (3DCT) reconstructions of 60 normal adult pelvises. 1 mm inferior and 1 mm lateral to the S1 dorsal foramen were chosen as the entry point, and ideal S2AI screw trajectories were explored by rotating and cutting the 3D pelvis, ensuring that the trajectories were of maximum length and width. The directions and depth of these determined trajectories were then measured.

Results The ideal S2AI screw trajectories could be found in each pelvis. The left and right screw trajectory parameters for males were shown as follows: angulation was L $29.15 \pm 8.60^\circ$ vs. R $29.96 \pm 8.28^\circ$ ($p = 0.286$) caudally in the sagittal plane and L $36.49 \pm 3.14^\circ$ vs. R $37.16 \pm 3.14^\circ$ ($p = 0.165$) laterally in the transverse plane. The maximal and intrasacral lengths of trajectory were L 121.25 ± 8.33 vs. R 120.63 ± 7.54 mm ($p = 0.460$) and L 26.20 ± 3.31 vs. R 26.92 ± 4.76 mm ($p = 0.268$). The entry point was L 28.87 ± 3.33 vs. R 29.79 ± 3.55 mm ($p = 0.186$) lateral to the second sacral midline, and L 44.14 ± 11.87 vs. R 43.89 ± 12.53 mm ($p = 0.687$) underneath the skin. The trajectories for females were more caudal (L: $34.50 \pm 6.56^\circ$ vs. $29.15 \pm 8.60^\circ$, $p = 0.009$; R: $35.72 \pm 7.53^\circ$ vs. $29.96 \pm 8.28^\circ$, $p = 0.007$) in the sagittal plane, but the lateral angulation in the transverse

plane showed no difference between genders ($p > 0.05$). The female iliac medullar cavities were obviously narrower than those of males (L: 14.76 ± 2.46 vs. 16.98 ± 3.52 , $p = 0.006$; R: 14.94 ± 2.60 vs. 17.00 ± 2.81 , $p = 0.005$). Although the average maximal length of trajectories for females were about 5 mm shorter than those of males, intrasacral length were equal to those of males. Furthermore, both the distance from entry point to the S2 midline and skin in the transverse plane showed no difference between genders. **Conclusion** The feasibility to insert S2AI screws to the sacrum and ilium in an Asian population along with the ideal entry angle and length of trajectory were identified for clinical practice.

Keywords Second sacral alar iliac (S2AI) screw · Three-dimensional computed tomography (3DCT) imaging · Neuromuscular scoliosis

Introduction

Severe scoliosis is very common in patients suffering from various neuromuscular conditions and can also be seen in patients with adult spinal deformities [1, 2]. In most patients, surgeries including pelvic fixation and correction of pelvic obliquity are required to regain spinal balance and improve spinal function [2–5]. Long spinal fusion to sacrum remains one of the most demanding challenges in terms of instrumentation. Traditional sacral fixations, including single sacral screw and S1–S2 bilateral sacral screws, take advantages of less soft tissue dissection and less surgical difficulty. However, the strength of these constructs is not as satisfied as expected, due to frequent implant failure, weak correction power for pelvic obliquity, and poor bone quality of the sacrum [6, 7].

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Iliac fixation with iliac screws is one of the most commonly used techniques to overcome these disadvantages. It may offer better pull-out strength than the Galveston technique [8] and allow easier placement of modular components in lieu of complex three-dimensional bending [3, 9, 10]. However, previous studies have shown that 44 % of the patients treated with iliac screws suffer from complications related to implant failure or prominence over the posterior superior iliac spine (PSIS) [11, 12], the loss of sacral fixation, loss of lumbar lordosis, and pseudarthrosis were all not unusual [13, 14]. In addition, subcutaneous soft tissue dissection is required in iliac screw technique to expose the ilium and perform placement of implants and connectors. This increases operation time, possibility of deep infection, and risks poor wound healing.

Compared with the above-mentioned traditional sacropelvic fixation technique with iliac screws, the S2AI screw fixation technique, initially devised contemporaneously by Sponseller and Kebaish for use in pediatric and adult population, has its own advantages. The S2AI screws are anchored to both the ilium and the sacrum with the purposes of obtaining immediate stability and proper biomechanical strength of constructs and of correcting pelvic obliquity with lower implant profile, less soft tissue dissection, and less complications [15].

Although the anatomic parameters in an American population have been previously analyzed [16], the application of S2AI screws in an Asian population has not been reported so far. The objective of this study is to determine the anatomical feasibility of placing S2AI screws in a Chinese adult population.

Materials and methods

Subjects

This is a cross-sectional study of 60 randomly selected skeletally mature patients who had their pelvic computed tomography (CT) scans performed to investigate hypogastralgia, retroperitoneal infection, or suspicion of pelvic neoplasms. In these subjects, no deformed or abnormal skeletal structure was found in both CT images and plain radiographs. We used systematic random sampling for selecting every 20th patient from a list generated from our hospital's Picture Archiving and Communication Systems (PACS) of patients who had been scanned from the beginning of January 2010 to the end of December 2011. Our study population consisted of 60 patients (30 males and 30 females) with a mean age of 46.1 years (range 20–60 years). Mean height of males and females were 173.26 ± 3.56 and 158.41 ± 3.42 cm, respectively. Mean weight of males were 64.52 ± 4.23 kg, while females were

57.67 ± 3.86 kg. All patients with metabolic bone diseases, past history of pelvic fractures, cancer, or instrumentation surgeries were excluded from the study. Each pelvis was radiographed to confirm normal and symmetric anatomy by X-ray. The present study was approved by the Clinical Research Ethics Committee of the Hospital.

CT reconstruction and radiographic parameters

Sixteen-slice CT (Light speed 16 systems, General electric company, American) was used to scan the whole pelvis with a layer thickness of 2.0 mm, voltage of 120 kV, and current of 220 mA. The reconstruction was performed with a pitch of 1 mm and threshold of 300 HU using Light speed workplace AW4.3 (General electric company, American), a matched CT imaging computer application was used for three-dimensional interactive viewing and manipulation.

CT imaging planes were rotated until they matched the ideal S2AI trajectory (greatest length and width of osseous channel) for patients. The entry point of screws was selected as 1 mm inferior and 1 mm lateral to the S1 dorsal foramen according to previous study [16] (Fig. 1a). Then the measurements were determined as follows:

1. Sag angle defined as caudal trajectory angulation in the sagittal plane (Fig. 1②, Angle I).
2. Tsv angle defined as lateral trajectory angulation in the transverse plane (Fig. 1③, Angle II);
3. Max-length defined as maximal distance of the trajectory from S2 ala to the anterior inferior iliac spine (Fig. 1③, Line III);
4. Sacral distance defined as intrasacral trajectory length (Fig. 1③, Line IV);
5. Iliac width defined as the narrowest iliac width measured between the inner cortices in the transverse plane (Fig. 1③, Line V);
6. S2 midline defined as the distance of the starting point lateral from the middle line of S2 (Fig. 1③, Line VI);
7. Skin distance defined as the distance of the starting point lateral from the skin (Fig. 1③, Line VII);
8. Iliac wing defined as the distance of the starting point lateral from the nearest iliac wing (Fig. 1③, Line VIII)

Since iliac screw technique chooses posterior superior iliac spine (PSIS) as the landmark, PSIS distance (defined as the distance from PSIS to nearest skin) was also measured. All measurements were performed bilaterally.

Statistical analysis

All measurements were analyzed by paired-samples' *t* test with SPSS 16.0 (SPSS Inc., Chicago, IL). On account of the differences in morphology between the pelvis of males

Fig. 1 Patient 15, male 44 years. ① CT 3D imaging. The starting point was 1 mm inferior and 1 mm lateral to the S1 dorsal foramen ② Sagittal reconstructed plane. I Sag angle: 16.24° ③ Transverse

plane. II Tsv angle: 32.23°, III Max-length: 123.60 mm, IV Sac distance: 29.66 mm, V Iliac width: 16.88 mm, VI S2 Midline: 30.52 mm, VII Skin distance: 30.23 mm and VIII Iliac wing: 11.59 mm

and females, independent-samples' *t* test was also used to detect possible divergence in the above-mentioned data between genders. Statistically significant differences were defined by $p < 0.05$.

Results

As shown in Table 1, the above-mentioned parameters were analyzed for the S2AI screw through three-dimensional radiographic analysis. The data from different genders were analyzed, respectively. Based on ideal virtual trajectories of males, the average Sag angle was $29.15 \pm 8.60^\circ$ on the left and $29.96 \pm 8.28^\circ$ on the right. The mean Tsv angle was $36.49 \pm 3.14^\circ$ for the left pelvis and $37.16 \pm 3.14^\circ$ for the right pelvis. Compared with the parameters of males, the trajectories of females were significantly more caudal with average Sag angle of $34.50 \pm 6.56^\circ$ ($p = 0.009$) on the left

side and $35.72 \pm 7.53^\circ$ ($p = 0.007$) on the right, while the bilateral Tsv angle showed no difference between genders ($p > 0.05$).

With respect to distance parameters, the average max-length was 121.25 ± 8.33 mm for the left and 120.63 ± 7.54 mm for the right, and the trajectories processed 26.20 ± 3.31 and 26.92 ± 4.76 mm before piercing the sacroiliac joint for the left and right pelvis, respectively, which was defined as sacral distance. Although average max-length of females was approximately 5 mm shorter than that of males, sacral distance showed no statistical difference. Bilateral iliac width along the optimal trajectory was 16.98 ± 3.52 mm on the left side and 17.00 ± 2.81 mm on the right side for males. For females, the pelvis showed narrower iliac width with an average difference of about 2 mm. Based on the ideal trajectory for the S2AI screw, the distance below the skin for S2AI screw insertion point showed no statistical differences between

Table 1 Parameters about S2AI screw trajectory (mean $\pm$ standard deviation)

Parameters	Males ($n = 30$)			Females ($n = 30$)		
	Left	Right	p	Left	Right	p
Sag angle($^{\circ}$)	29.15 $\pm$ 8.60*	29.96 $\pm$ 8.28*	0.286	34.50 $\pm$ 6.56	35.72 $\pm$ 7.53	0.105
Tsv angle($^{\circ}$)	36.49 $\pm$ 3.14	37.16 $\pm$ 3.14	0.165	35.72 $\pm$ 3.79	36.27 $\pm$ 3.27	0.367
Max-length (mm)	121.25 $\pm$ 8.33*	120.63 $\pm$ 7.54*	0.460	114.75 $\pm$ 9.44	115.67 $\pm$ 8.24	0.461
Sacral distance (mm)	26.20 $\pm$ 3.31	26.92 $\pm$ 4.76	0.268	27.74 $\pm$ 6.02	27.95 $\pm$ 5.17	0.764
Iliac width (mm)	16.98 $\pm$ 3.52*	17.00 $\pm$ 2.81*	0.975	14.76 $\pm$ 2.46	14.94 $\pm$ 2.60	0.608
S2 midline (mm)	28.87 $\pm$ 3.33	29.79 $\pm$ 3.55	0.186	28.28 $\pm$ 3.61	28.98 $\pm$ 3.67	0.206
Skin distance (mm)	44.14 $\pm$ 11.87	43.89 $\pm$ 12.53	0.687	48.12 $\pm$ 12.93	47.81 $\pm$ 14.05	0.693
Iliac wing (mm)	7.02 $\pm$ 2.98*	7.42 $\pm$ 1.23*	0.787	10.46 $\pm$ 2.78	10.09 $\pm$ 2.02	0.429
PSIS distance (mm)	15.83 $\pm$ 8.63*	16.30 $\pm$ 8.47*	0.435	23.25 $\pm$ 10.22	23.12 $\pm$ 9.89	0.883

* data was statistically different from that of females ($p < 0.05$)

males and females. However, the entry points of males away from the iliac wing were 3 mm longer than those of females on both sides. Figures 1 and 2 demonstrate cases of all these measurements mentioned above.

Discussion

Although new screws and connectors have been designed and various instrumentation methods have been developed in practice, sacropelvic fixation remains a surgical challenge, especially in neuromuscular scoliosis and severe adult scoliosis [11]. Multiple studies have shown that long instrumentation to the sacrum without supplemental pelvic fixation predisposes to implant failure [17–19]. Methods of fixation to achieve effective iliac fixation have evolved over from Galveston technique to iliac screws in recent decades. However, these techniques often require soft tissue dissection for the placement of screws or the use of connectors. Spinopelvic instrumentation through S2AI screw is supposed to be an alternative, low-profile, and effective technique.

Although the traditional S1 screws with or without S2 screws were most satisfactory for short instrumentations involving the lumbosacral spine, it was reported that with longer instrumentations passage of the rod through the holes of two adjacent sacral screws became more difficult and the screws may loosen [14]. Both biomechanical and clinical results suggested that the failure of instrumentation such as pull-out of the screws may occur because of the short screw length and large component of cancellous bone in sacrum. In addition, it is difficult to correct pelvic obliquity in neuromuscular or adult scoliotic patients [6, 20]. The Galveston technique has been suggested to provide unstable fixation and worsening of pelvic tilt with more iliac anchor motion and is also associated with up to 32 % of complications due to the long lever arm and the

high loads placed on the lumbosacral area and fixation device [3, 21]. According to previous studies, S2AI screw fixation technique has more fixed segments and stable biomechanical torsion due to the direction and the length of the screws, leading to more reliable stability compared to traditional iliac screw fixation. McCord DH et al. [22] confirmed that compared to traditional S1 screw fixation, S2AI fixation could achieve more inferior purchase by extending the fixation down to the S2 pedicle. As the PSIS is the most caudal aspect of iliac screw technique, the S2AI screw fixation technique could provide additional purchase by producing a mean distance of 26.20 (left) and 26.92 mm (right) inside the sacrum at the second sacral level. He also demonstrated that more stability could be achieved if the movement of fixation can be distributed as far anteriorly and laterally to the spine as possible [22]. S2AI screw technique achieves this goal better than iliac screw technique and improved the construct stability due to its longer screw length.

Except for the biomechanical stability, S2AI screw technique can also reduce the complications compared to traditional fixation [15]. In iliac screw procedure, iliac crest bone harvesting will damage the traditional fixation technique due to the anatomic proximity of harvest site to the implant insertion [23]. However, the S2AI procedure is less likely to be effected by iliac crest bone harvesting because of its anterior position of anchoring in the ilium. In addition, the iliac screw technique requires extensive surgical exposure of the PSIS with minimal soft tissue cover which may cause a higher risk of blood loss as well as infection rate which has been reported as 4 % associated with iliac fixation [24]. However, the S2AI screw technique may minimize blood loss and infection rate by avoiding soft tissue damage around the PSIS, because the implants can be completely covered by an intact layer of muscle and minimally disturbed skin. According to previous research, the starting point of S2AI screw (1 mm inferior and 1 mm

Fig. 2 Patient 46, female 23 years. ① CT 3D imaging. The starting point was 1 mm inferior and 1 mm lateral to the S1 dorsal foramina. ② Sagittal plane. I Sag angle: 39.84°. ③ Transverse plane. II Tsv

angle: 33.13° III Max-length: 120.7 mm. IV Sac distance: 24.57 mm. V Iliac width: 11.90 mm. VI S2 Midline: 24.70 mm. VII Skin distance: 41.93 mm. VIII Iliac wing: 9.14 mm

lateral to the S1 dorsal foramen) is in line with lumbar and S1 pedicle anchors [15, 25, 26]. This allows easier linkage of the S2AI screws and proximal instrumentation with less connector which consequently decreases both operation time and blood loss.

In the present study, ideally, the max-length of S2AI trajectories ranges from L105.7/R108.3 to L137.2/R142.7 mm for males, and from L95.4/R94.3 to L132.1/R128.1 mm for females. Peelle et al. [3] demonstrated that the length of iliac screws, depending on the morphology of the pelvis, varied from 50 to 75 mm in practice. This indicates that the ideal S2AI trajectory exceeds the length usually used on market regardless of possible screw options. Whether the S2AI screws can penetrate the ideal iliac plane smoothly mainly depends on the iliac width. This study shows that the iliac width of the determined transverse plane ranged from L11.06/R12.43 to L24.63/R24.63 mm. Therefore, currently available screws with a maximal diameter of 7.5 mm could penetrate the iliac medullary cavity without an impingement if the direction is accurate. Although iliac

width of females is a little narrower (2 mm less averagely), the minimum width of L8.15/R9.42 mm also accepts S2AI screws with a diameter of 7.5 mm. The mean skin distance for the S2AI technique was about 30 mm for males (range L: 15.83–44.14 mm; R: 16.30–43.89 mm) and 25 mm for females (range L: 23.25–48.12 mm; R: 23.12–47.81 mm), deeper than the PSIS skin distance for iliac screw technique. According to the present study, the authors recommend insertion of the S2AI screws with a Sag angle of $L29.15 \pm 8.60^\circ/R29.96 \pm 8.28^\circ$, and Tsv angle of $L36.49 \pm 3.14^\circ/R37.16 \pm 3.14^\circ$. Specifically, S2AI screws of females should be placed 5° more caudally than males. Recently, Kwan et al. [27] conducted a study of sacral screws insertion in which S2AI screw was included, and Tsv angle and max-length of S2AI screws were measured. Max-length was similar to our result (male 122.60 vs. 121.25 mm; female 122.2 vs. 120.63 mm), but Tsv angle was a little larger (male 39.3° vs. 36.49°; female 39.50° vs. 37.16°). Any excessive deflection of the S2AI screw may puncture the sacral or iliac cortex, damaging the tissues proximal to the

Table 2 Summary of previous published S2AI screws parameters

Author	Chang TL		O'Brien JR		O'Brien JR	
Population	American		American		American	
Age	12–18 years		–		–	
Subjects	Adolescent with normal pelvis		Cadaver		Cadaver	
Methods	Radiographic simulation		Instrumentation		Instrumentation	
Gender	M (n = 13)	F (n = 7)	M (n = 5)	F (n = 5)	M (n = 4)	F (n = 4)
Sag angle(°)						
L	36.73	41.56	32.62	36.82	25.98	23.05
R	37.44	41.94	31.4	32.44	32.75	35.00
Tsv angle(°)						
L	39.44	37.97	51.18	39.16	38.78	44.30
R	40.58	41.06	36.76	36.58	41.00	45.00
Max. length (mm)						
L	105.87	106.89	76.00	76.00	103.10	103.53
R	102.96	104.93	92.00	92.00	75.95	87.33
Sacral distance (mm)						
L	36.35	33.79	4.51	4.39	24.93	31.03
R	34.32	33.09	3.88	4.14	31.55	31.38
Iliac width (mm)						
L	12.22	12.83				
R	12.47	11.58				

pelvis which may be catastrophic. Excessive caudal insertion of screws is likely to damage the neurovascular structures underneath the greater sciatic notch, including sciatic nerve and superior and inferior gluteal artery/vein/nerve [28]. Sponseller et al. [15] reported a case of asymptomatic break at the neck of a 7-mm S2AI screw at 2-year follow-up. The sacroiliac joint is an amphiarthrodial joint, and fracture of S2AI screws may occur during a long period of fretting [15]. To avoid this, abundant bone graft around the sacroiliac joint area is absolutely necessary.

In addition, it needs emphasizing that all the data we obtained were based on population with relatively healthy spine who were diagnosed without deformed skeletal structure and that the data should be used to guide screws insertion in patients without pelvic obliquity or pelvic asymmetry. Matteini et al. [29] reported a case of postlaminectomy degenerative scoliosis with bilaterally insertion of S2AI screws. In this case report, angulation was directed toward the greater trochanter and approximately 30° anterior from the floor, and corresponding data in the present study is Sag angle which is around 29°. According to Matteini's experience, it would be at 35–40 mm before the ilium is reached, and we demonstrated the average sacral distance was 26–27 mm in Chinese population. The screw used in the case report was 7 × 80-mm screw, which corresponds to the result of the present study.

Moreover, this study is based on a Chinese population. We retrospectively reviewed the parameters of S2AI screws from previous studies and found that ethnic and sex differences may affect the parameters of S2AI screw insertion (Table 2). Compared to an American population, the average Sag angle and Tsv angle of a Chinese population were also around 30–40°, while the average max-length was about 120 mm for males and 115 mm for females in a Chinese population, which obviously exceeded previous results for an American population as shown in Table 2. In other words, ethnic difference may affect the choice of screw size.

In summary, it is feasible for S2AI screws to be used in Chinese adult patients. Optimal position requires insertion at approximately 1 mm inferior and 1 mm lateral to the S1 dorsal foramen through the sacroiliac joints and iliac wings with approximately 30° of caudal angulation in the sagittal planes (5° more for females) and 36° of lateral angulation in the transverse plane. S2AI screw technique has theoretical advantages over traditional sacropelvic fixation techniques; however, the technique of S2AI screw placements are still demanding and challenging.

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Conflict of interest None.

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