# The three-dimensional printed template guided technique for S2AI screw placement and a comparison with freehand technique

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# Abstract

Background Sacropelvic fixation continues to present challenges when involved in the adult spinal deformity correction. The S2 alar iliac (S2AI) fixation is commonly used in sacropelvic fixation. Several techniques, including intraoperative navigation and freehand technique, were used for S2AI screws placement. The aim of this study is to analyze the anatomic parameters for S2AI screw trajectory in Asian population and introduce a novel technique described as three-dimensional printed template guided technique (TGT). Meanwhile, the accuracy and safety of this technique were compared with conventional freehand technique. Methods The S2AI trajectory parameters were measured in100 Asian adult volunteers. Parameters were compared between different genders. Forty-eight adult patients who underwent S2AI screw placement were reviewed, 28 patients received freehand technique and 20 patients received TGT technique. Postoperative CT was used to assess the accuracy of screw trajectory and cortex violation related complications were recorded. Results The cephalocaudal angles (CA), maximal length of screw pathway (ML), narrowest width of pathway within the iliar teardrop (NW), distance from the center of teardrop to sciatic notch(SD) and distance of the start point distal to S1 dorsal foramen(DD) showed significant gender-related difference ($p<0.05$). All 48 patients were placed S2AI screws bilaterally (40 screws in TGT vs 56 screws in freehand). One screw penetrated iliac cortex in TGT group but 10 screws penetrated iliac cortex in freehand group (3% vs 17.9%) ($p<0.05$). Conclusion Approximately 30-35° of cephalocaudal angle and 39°mediolateral angle are appropriate for S2AI screw placement in Asian patients. Either freehand or TGT technique is safe for S2AI screw placement. TGT technique is more accurate compared with conventional freehand technique. Trial registration This is a retrospective study.


Key words Sacropelvic fixation, Second sacral alar iliac (S2AI) screw, three-dimensional printed template, freehand technique


# Background

Spinopelvic fixation plays an integral role in achieving solid osseous fusion across the lumbosacral junction, especially in deformity procedures requiring substantial correction or long-segment constructs. [1, 2]There are several techniques for spinopelvic fixation that include Galveston technique[3], iliac screws (iliac bolts), iliosacral screws, and S2 alar iliac screws (S2AI) technique[1, 4] Compared with other pelvic fixation techniques, S2AI screws has been developed to be a prevailing alternative spinopelvic fixation technique due to the advantages of keeping screw tail away from the skin, no incision overexposure, more excellent pull-out strength and standing on the same longitudinal line of lumbar pedicle screws[5, 6]. However, S2AI technique is still challenging to less experienced spine surgeons who have no navigation system available. Inadequate accuracy of screw implantation is potential to result in surgery-related complications[7]. The incidental cortical breach of an S2AI screw may not only result in decreased fixation strength but also injury to the major vessels, particularly the internal iliac artery and the superior gluteal artery when breaching anteriorly and caudally. Injuries of these major vessels could lead to major intrapelvic hemorrhage, which is a life-threatening complication[8]. Therefore, surgeons should avoid anterior or caudal deviation during screw insertion to achieve safe insertion of S2AI screws. The anatomic parameters in American population have been previously analyzed[9], but in Asian population remains unclear. The aim of this study is to analyze the anatomic parameters for S2AI screw placement in Asian population and introduce a novel technique depends on these parameters described as three-dimensional printed template guided technique (TGT). The accuracy and safety of this technique compared with conventional freehand technique were also evaluated.

## Methods

From Oct 2014 to March 2015, 100 Chinese adult volunteers were recruited to measure the S2AI trajectory. They were 56 males and 44 females with a mean age of 51.6±7.1 years old. We defined the optimal trajectory of the screw to be determined by the line connected the start point and the center of cross section of teardrop above sciatic notch. The start point was located lateral to the midpoint between S1 and S2 dorsal foramina and standing on the extending line from L5 and S1 pedicle screw anchor points. Then we used UG software to mimic the optimal trajectory and measured the following parameters were described as following (Figure 1). All the parameters were compared between different genders.

1. Cephalocaudal angles (CA), defined as caudal trajectory angulation in the sagittal plane.
2. Mediolateral angles (MA), defined as lateral trajectory angulation in the transverse plane.
3. Maximal length of screw pathway (ML), defined as maximal length of the screw trajectory in pelvis.
4. Narrowest width of screw pathway (NW), defined as the narrowest canal width along the pathway.
5. Distance from the center of cross section of teardrop above sciatic notch to sciatic notch (sciatic notch distance, SD).
6. Distance of the start point to midline (midline distance MD), defined as the distance of the start point away from the midline.
7. Distance of the start point inferior to S1 dorsal foramen (dorsal foramen distance, DD).

Meanwhile, from Apr 2015 to Oct 2017, 48 patients with degenerative scoliosis, lumbosacral chronic infection or tuberculosis, who underwent posterior lumbopelvic reconstruction with S2AI screw technique, were retrospectively reviewed. They were 26 males and 22 females with an average age of 58.3±10.5 years old. Among of these 48 patients, 28 patients received freehand technique and 20 patients received TGT technique for S2AI screw placement. All the patients received pre- and postoperative pelvis CT.

# Surgical procedure

Screw placement began with meticulous subperiosteal dissection of the posterior elements and exposed anatomic landmarks including the S2AI start point. In freehand group, the start point was located lateral to the midpoint between S1 and S2 dorsal foramina and standing on the extending line from L5 and S1 pedicle screw anchor points, and the following procedures were described by Kebaish and Sponseller previously[9-11]. In TGT group, the parameters of the optimal trajectory mentioned above were analyzed by the post-processing software and individualized 3D template was designed and printed(Figure 2). In the surgical procedure, the start point is as same as the abovementioned. All soft tissues were thoroughly dissected and dorsal foramen of S1 and S2 were clearly exposed, the printed 3D guide template was closely matched to the sacral dorsal bone surface. It is crucial to closely match the guide template with the bone surface, which could guide the 2.5mm K-wire to be drilled forward along the optimal trajectory. Otherwise, the TGT technique should be given up if the template could not closely match the bone surface. After checking the position of the K-wire, tapped the track along K-wire, then removed K-wire and placed the screw along the track(Figure 3).

# Postoperative accuracy evaluation of screw placement

Fine-cut (width of 1mm) CT is used to assess the accuracy of screw placement after surgery. We define that the screw contained between the lateral and medial iliac cortex as being accurately placed. By contrast, screw that violated or broke medial or lateral cortex, –or the sciatic notch was defined as being inaccurately placed. The screw breach were divided into 4 grades according to the previous description by Oh CH [12]. No screw breach was defined as grade 0; The screw breach distance away from the cortex less than 3mm was defined as grade 1 (mild), 3-6mm as grade 2 (moderate), more than 6mm as grade 3 (severe). The screws breaches are considered unqualified screws placement. All measurements were assessed bilaterally.

# Statistical analysis

Data are presented as the mean ± standard deviation. For the optimal trajectory, the independent sample t-test was performed to detect possible divergence of the parameters between genders. And the chi-square test was used to determine the different results in comparison between freehand with TGT technique. Statistical significance was defined as p value < 0.05. Analysis was conducted by using SPSS 17.0 (SPSS Inc., Chicago, IL).

## Results

Ideal S2AI trajectory parameters were obtained based on all volunteers. There is no statistical difference between the left and right sides of the same gender. The CA, MA, ML, NW, SD, MD, DD and KD were 29.21° ±6.52°, 39.75°±2.40°, 110.3 ± 7.22 mm, 16.60 ± 2.51 mm, 11.58 ± 1.18 mm, 26.5 ± 1.88 mm, 5.18 ± 1.08 mm, 39.25 ± 11.98 mm in males, and 35.21°±6.86°, 40.38 ± 3.58°, 102.64 ± 14.28 mm, 13.86 ± 2.65 mm, 10.83 ± 1.48 mm, 25.95 ± 1.28 mm, 4.60 ± 0.83 mm, 44.31 ± 9.20 mm in females, respectively. Among of these parameters, SA, ML, NW, SD and DD showed significant sex-related difference ($P < 0.05$) (Table 1). Additionally, there is no significant age-related difference in all parameters. Bilateral S2AI screws were placed in all 48 patients and 96 screws were placed in total. (Table 2). There is no cortex violation related complications occurred in all patients. One screw were placed with penetrated iliac cortex in TGT group (3%, 1/39) but ten screws were placed with penetrated iliac cortex in freehand group (17.9%, 10/56). There is a significant different between two groups. ($P < 0.05$) (Table 3)(Fig. 4).

Table 1
Parameters of optimal trajectory and comparison between different genders

| parameters | Males(n = 56) | Females(n = 44) | P value |
|---|---|---|---|
| CA (°) | 29.21 ± 6.52 | 35.21 ± 6.68 | 0.001 |
| MA (°) | 39.75 ± 2.40 | 40.38 ± 3.58 | 0.425 |
| ML (mm) | 110.30 ± 7.22 | 102.64 ± 14.28 | 0.011 |
| NW (mm) | 16.60 ± 2.51 | 13.86 ± 2.65 | 0.0001 |
| SD (mm) | 11.58 ± 1.18 | 10.83 ± 1.48 | 0.036 |
| MD (mm) | 26.50 ± 1.88 | 25.95 ± 1.28 | 0.191 |
| DD (mm) | 5.18 ± 1.08 | 4.60 ± 0.83 | 0.023 |

Note: cephalocaudal angles (CA), mediolateral angles (MA), maximal length of pathway (ML), narrowest width of the ilium along this pathway (narrowest width, NW), distance of the center of teardrop to sciatic notch (SD), distance of the start point to midline (MD), distance of the start point to inferior S1 dorsal foramen (DD)

Table 2
Demographics of the patients

| Characteristics | Freehand group | TGT group | Value of t or X2 | p value |
|---|---|---|---|---|
| No. of Cases | n = 28 | n = 20 | $X^2 = 0.10$, | p = 0.578 |
| | Male = 15 | Male = 11 | | |
| | Female = 13 | Female = 9 | | |
| Mean age (y) | 63.7 ± 12.6 | 57.8 ± 9.5 | t = 1.764 | p = 0.084 |
| Weight (kg) | 76.7 ± 7.5 | 72.9 ± 8.3 | t = 1.655 | p = 0.105 |
| Height (cm) | 170.3 ± 5.9 | 166.9 ± 6.2 | t = 1.911 | p = 0.062 |
| BMI (kg/m$^2$) | 26.4 ± 1.8 | 26.1 ± 2.1 | t = 0.531 | p = 0.598 |
| Diagnosis | | | | |
| Adult Spinal deformity | 20 | 18 | | |
| Lumbosacral infection | 3 | 1 | | |
| Lumbosacral TB | 5 | 1 | | |
| No. of Screws | 56 | 40 | | |
| Breaches | 10 | 1 | | |
| Posterior | 8 | 1 | | |
| Anterior | 2 | 0 | | |
| Inferior | 0 | 0 | | |

Table 3
The comparison of the accuracy between freehand technique and TGT technique

| Variable | Total screws | Result | | | | $X^2$ | P |
|---|---|---|---|---|---|---|---|
| | | 0(0mm) | 1(mild) | 2(moderate) | 3(severe) | | |
| Freehand | 56 | 46 | 4 | 4 | 2 | 5.424 | 0.020 |
| TGT | 40 | 39 | 1 | 0 | 0 | | |

# Discussion

Achieving pelvic fusion across the lumbosacral junction with S2AI screw can be challenging for less-experienced surgeons in management of spinal deformity[4]. Compared to other sacropelvic fixation techniques, S2AI technique has several theoretical merits including lower rate of implant failure and less surgical revisions. Additionally, the S2AI screw technique precludes the need for cross-connectors[9, 4], which can significantly reduce the incidence of screw loosening. With lower screw prominence and deeper subcutaneous locations, S2AI screws are covered by full-thickness skin and subcutaneous tissue, which can significantly reduce the incidence of local skin ulceration and deep infection[5, 6]. Furthermore, the direction and the length of the S2AI screw sacropelvic fixation provides more reliable stability compared to traditional iliac screw fixation[13, 14]. However, in spite of emerging clinical evidence demonstrating the advantages of S2AI screws, the accuracy of S2AI screw placement remains concerns. The accuracy of S2AI screw placement depends on pelvic anatomic landmarks and trajectory.

Two start point were recommended for S2AI screw placement. One is the midpoint between the S1 dorsal foramen and the S2 dorsal foramen where they meet the lateral sacral crest. The other is 1 mm inferior and 1 mm lateral from the S1 dorsal foramen. Two start points have different safety margins. However, in most cases, the difference between the two start points was considered negligibly in terms of safe screw insertion[8]. In this study, the point which was located lateral to the midpoint between S1 and S2 dorsal foramina and standing on the extending line from L5 and S1 pedicle screw anchor points was adopted as a start point and the optimal trajectory of the screw to be determined by the line connected the start point and the canal center of teardrop. The result showed that the CA of optimal trajectory is on average of 29.21°±6.52° in males and 35.21°±6.86° in females. CA presented significant differences between males and females. This result is consistent with a previous study from Zhu et al, a radiographic study assessing optimal S2AI screw placement and presented that CA in females have 4 to 5 degrees more caudal trajectory compared with males[15]. But a study from Shillingford showed there is no significant differences in the CA or MA between females and males[2]. This study showed there is no difference in MA between males and females with an average 40° (39.75°±2.40° vs 40.38 ± 3.58°). This result is also consistent with previously studies[16]. Based on this, the author recommended that S2AI screws of females should be placed 5 degree more caudally than males.

Whether the S2AI screws can penetrate the ideal iliac plane smoothly mainly depends on the iliac width, which is described as the narrowest width of pathway within the iliar teardrop (NW). Previous studies defined the standard S2AI screws ranges from 70 to 100 mm in length and 5.0 to 7.5 mm in diameter[17, 10]. A study from Wang showed that the iliac canal width ranged from 17.4 to 32.4 mm in males and 13.5 to 20.3 mm in females in Chinese population. They suggested that that screws ranging from 5.0 to 7.5 mm in diameter can be appropriate[18]. This study showed that the NW was 16.60 ± 2.51 mm in males and 13.86 ± 2.65 mm in females. Although in females, the canal showed narrower with an average difference of about 3 mm the frequently-used screws in the clinical could go through the iliac canal without difficulty.

In the present study, the ML, SD and DD showed significant sex-related difference. These parameters depend on the morphology of the pelvis, varied from 50 to 75 mm in practice [19]. In our study, the ML were 110.3 ± 7.22 mm in males and 102.64 ± 14.28 mm in females. The average max-length of trajectory in females was approximately 8 mm shorter than that in males. Compared with previous study from Zhu et al[15], ML is different from their investigation in which the average max-length of trajectory in females was approximately 5 mm shorter than that in males. In clinical practice, the optional S2AI trajectory exceeds more the length of usually-used screw. Although O'Brien et al consider that 65 mm length S2AI screw were equivalent to 80 mm length S2AI screw in respect of providing biomechanical purchase [20], using longer screw was much more in surgery may consider the long term stability of sacropelvic fixation particularly in long range fusion. And if the stress of longer screw fixation can be distributed as far anteriorly and laterally to the spine as possible, more stability could be achieved[14, 13].

Based on the optimal S2AI screw trajectory, we used software to design 3D printed template to guide S2AI screw placement individually to avoid the screw penetration which might arise screw-related complications. Compared with freehand group, in which ten screws penetrated iliac cortex, only one screw penetrated iliac cortex in TGT group. The accuracy rate of the freehand and TGT group are 82.1% and 97.5%, respectively. The TGT technique is quite accurate. Additionally, other merits can also be obtained via TGT technique. There is no need to probe to identify the integration of the track canal repeatedly, which could save surgery time. Second, CA and MA more rely on the surgeon's subjective estimation during surgery because of without objective measurement tool when placing S2AI screw in freehand technique, and there still has mal-positioned screws even under repeated fluoroscopy. So, TGT technique could surely decrease radiation exposure. Finally, the TGT technique is easier to study for less-experienced surgeons who are not familiar with the complexomorphic pelvis, and easier to place the screw even for experienced surgeons when facing anatomically abnormal pelvis which is not rare in congenital deformity.

There are some limitations in this study. The parameters of optimal trajectory analyzed in our study were based on Chinese population. It is crucial to closely match the guide template with the bone surface, otherwise, the technique has to be abandoned because of the potential wrong direction guided by the template. The material for printing template and the precision of printing machine would influence the quality of template. Another limitation is that practitioner need extra-time to design the individual template if plan to perform TGT technique.

# Conclusion

Optimal position for S2AI screw placement in Chinese adult patients is starting at approximately 1 mm inferior and 1 mm lateral to the S1 dorsal foramen and go through the sacroiliac joints with approximately 30 degrees of CA (5 degrees more in females) and 39 degrees MA. Additionally, either freehand or TGT technique is safe for S2AI screw placement. TGT technique is more accurate compared with freehand technique.

# List Of Abbreviations

S2 alar iliac  S2AI

three-dimensional printed template guided technique  TGT

Computed Tomography CT

Cephalocaudal angles CA

Mediolateral angles MA

Maximal length of screw pathway ML

Narrowest width of screw pathway NW

Sciatic notch distance SD

Distance of the start point inferior to S1 dorsal foramen DD

# Declarations

### Ethics approval and consent to participate

This study was approved by Ethic Committee of The Second Affiliated Hospital of Nanchang University.

### Consent for publication

Written informed consent was acquired from each of volunteers and patients to authorize treatment, imageology findings, and photographic documentation. The patients consented to the publication of their pictures as well as their anonymous and clustered data.

### Availability of data and materials

The datasets analyzed during the current study are not publicly available because a further study is processing but are available from the corresponding author on reasonable request.

### Competing interests

The authors declare that they have no competing interests.

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### Authors' contribution

Kai Cao and Zhenhai Zhou contributed to the conception. Zhenhai Zhou contributed to the designs and draft of the work and revised it critically for important intellectual content. Zhimin Zeng, Honggui Yu and

Jiachao Xiong did the acquisition of data of the work. Zhimin Liu, Rongping Zhou, Wenbing Wan, Zhimin Pan and Lu Chen did the analysis and interpretation of data of the work. Kai Cao approved the version to be published. Kai Cao agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors read and approved the final manuscript.

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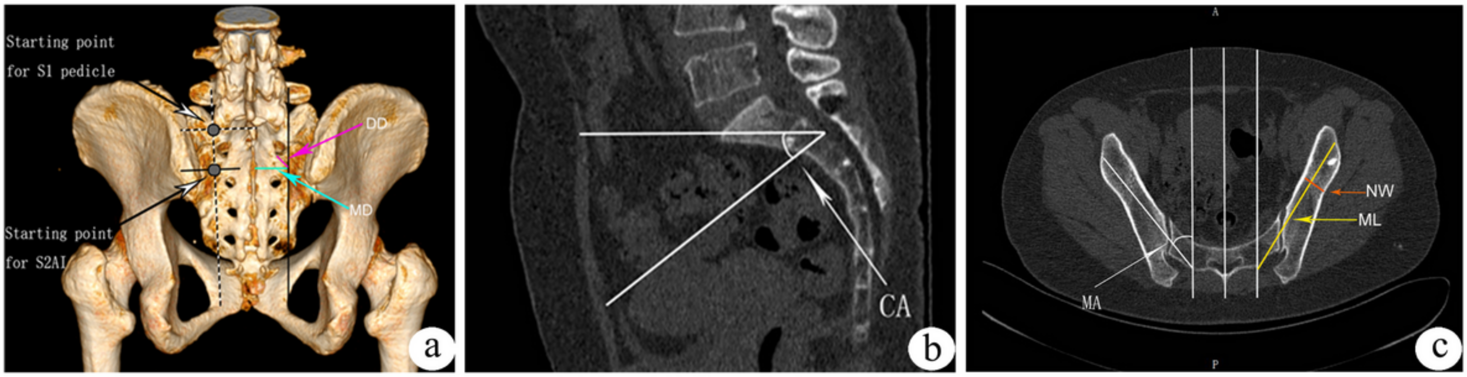
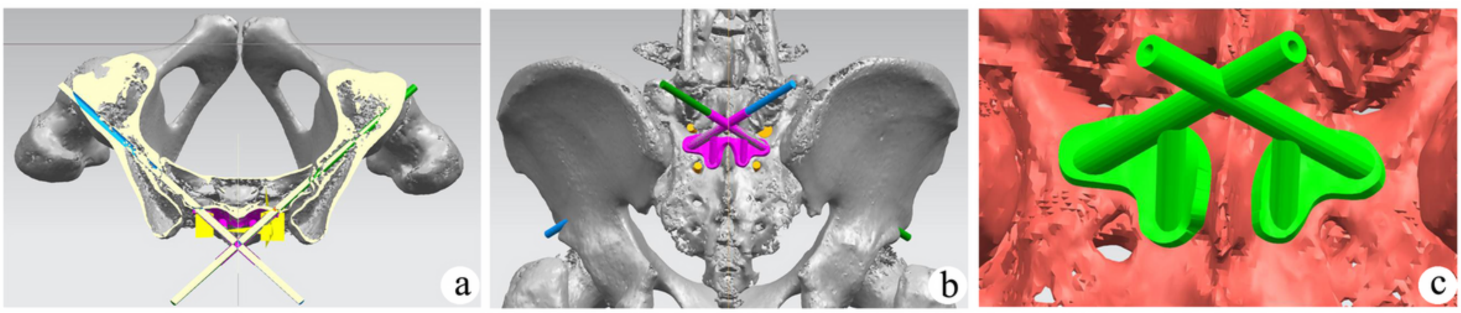
# Figures



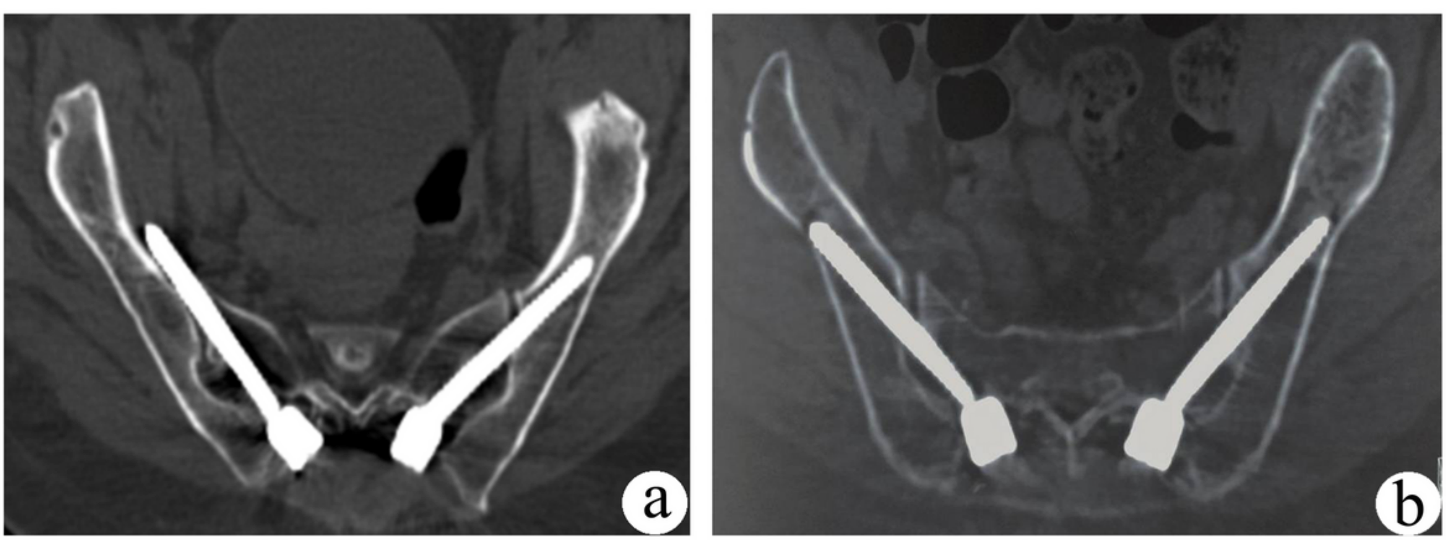

## Figure 1

Parameters for S2AI screws placement. Posterior view of 3D CT image. Fig1a showed that the start point of S2AI was located lateral to the midpoint between S1 and S2 dorsal foramina and standing on the extending line from L5 and S1 pedicle screw anchor points. MD is defined as the distance of the start point away from the midline and DD is defined as the distance of the start point inferior to S1 dorsal foramen. Fig1b showed the CA. Fig1c showed the MA, ML and NW.




## Figure 2

A 3D view of the optimal trajectory and printed template. Fig2a showed the optimal S2AI trajectory from axial view. Fig2b showed the S2AI trajectory from posteoanterior view and the designed template. Fig2c show a virtual printed template.



## Figure 3

Intraoperative procedures. Fig3a showed a template was closely matched with the bone surface after all soft tissues were thoroughly dissected and dorsal foramen of S1 and S2 were clearly exposed. Fig 3b showed a K-wire (2.0mm) was drilled along the guided template across the sacroiliar joint and into the ilium

## Figure 4

The positions of S2AI screws placed by two techniques. Fig4a showed a screw penetrated the medial iliar cortex by freehand technique. Fig4b showed an excellent screw position by TGT technique.