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ORIGINAL PAPER

A computed tomographic anatomical study of the upper sacrum. Application for a user guide of pelvic fixation with iliosacral screws in adult spinal deformity

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Abstract

Purpose Widely used in traumatic pelvic ring fractures, the iliosacral (IS) screw technique for spino-pelvic fixation remains anecdotal in adult spinal deformity. The objective of this study was to assess anatomical variability of the adult upper sacrum and to provide a user guide of spino-pelvic fixation with IS screws in adult spinal deformity.

Methods Anatomical variability of the upper sacrum according to age, gender, height and weight was sought on 30 consecutive pelvic CT-scans. Thus, a user guide of spino-pelvic fixation with IS screws was modeled and assessed on ten CT-scans as described below. Two invariable landmarks usable during the surgical procedure were defined: point A (corresponding to the connector binding the IS screw to the spinal rod), equidistant from the first posterior sacral hole and the base of the S1 articular facet and 10 mm-embedded into the sacrum; point B (corresponding to the tip of the IS screw) located at the junction of the anterior third and middle third of the sacral endplate in the sagittal plane and at the middle of the endplate in the coronal plane. Point C corresponded to the intersection between the A-B direction and the external facet of the iliac wing. Three-dimensional reconstructions modeling the IS screw optimal direction according to the A-B-C straight line were assessed.

Results Age had no effect on the anatomy of the upper sacrum. The distance between the base of the S1 superior articular facet and the top of the first posterior sacral hole was correlated with weight ($r = 0.6$; 95% CI [0.6–0.9]); $p < 0.001$). Sacral endplate thickness increased for male patients ($p < 0.001$) and was strongly correlated with height ($r = 0.6$; 95% CI [0.29–0.75]); $p < 0.001$) and weight ($r = 0.8$; 95% CI [0.6–0.9]); $p < 0.001$). The thickness of the inferior part of the S1 vertebral body increased in male patients ($p < 0.001$). Other measured parameters slightly varied according to gender, height and weight. Simulating the described technique of pelvic fixation, no misplaced IS screw was found whatever the age, gender and morphologic parameters.

Conclusion This user guide of spinopelvic fixation with IS screws seems to be reliable and reproducible independently of age, gender and morphologic characteristics but needs clinical assessment.

Level of evidence: Level IV

Keywords CT-scan · Sacral foramina · Sacrum · Iliosacral screw · S1 root

Abbreviations

CI	confidence interval
CT-scan	computed tomography
First sacral foramina	S1–2 foramina

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IS	iliosacral
SEM	standard error of the mean

Introduction

In regards to adult spinal deformity, pelvic fixation remains a challenging procedure potentially increasing surgical morbidity [1, 2]. Numerous types of pelvic fixation were successively developed but none has demonstrated superiority over other methods [3, 4].

Iliosacral (IS) screw placement was initially used in traumatology to reduce and stabilize vertical IS disruptions [5–7]. The interest of IS screw fixation is nowadays well established as it can be percutaneously performed with a small implant biomechanically equal or superior to other techniques of internal fixation [8–11]. Dubousset et al. [12] developed a type of spino-pelvic fixation with IS screws to correct pelvic obliquity in patients with neuromuscular scoliosis. This device combines an IS screw bound to the rod of a posterior spinal instrumentation by a polyaxial connector (Fig. 1) [13].

Nevertheless, the use of spino-pelvic fixation with IS screws in adult spinal deformity remains anecdotal [3, 14]. No study has clearly established a reliable method to place IS screws in this case. Unlike what is commonly performed for traumatic pelvic ring fractures, fluoroscopically guided surgery using inlet and outlet views is not applicable for spino-pelvic fixation with IS screws. Besides, computer-assisted surgery, although safe, is not yet widespread and few surgical centres are equipped.

To this date, only two authors reported clinical and radiographic outcomes following pelvic fixation using IS screws: spino-pelvic fixation with IS screws in adult spinal deformity showed favourable results in their studies [3, 14]. This type of spino-pelvic fixation was transposed from paediatric surgery to adult surgery but the anatomical landmarks between a paediatric neuromuscular pelvic ring and a normal adult pelvic ring are supposedly different [15–17]. The main risk is to generate a conflict with the S1 roots in their sacral foramina [18, 19].

Numerous authors have already assessed the anatomy of the upper sacral bones: sacral pedicles, S1 foramina and sacral bone density were the most studied items [20–28]. However, few authors have sought variations of the upper sacral anatomy according to gender [29, 30] and none according to patient morphologic characteristics. The study was conducted using data collected from CT-scans [31] and had three goals:

1. To analyze the anatomy of the upper sacrum in an adult population region of interest because the IS screw extends through the S1 vertebra body.
2. To establish an user guide of spino-pelvic fixation with IS screws in adults (Fig. 1 C)
3. To seek an effect of age, gender, weight and height on the anatomy of the upper sacrum and the IS screw placement.

Materials and methods

Population setting

Forty consecutive pelvic CT-scans were included: 30 for the analysis of the upper sacral anatomy and ten to assess a user guide of spino-pelvic fixation with IS screws. Patients under 18 years old or presenting a lumbosacral transitional vertebra, a history of sacral or pelvic ring fracture, an L5-S1 isthmic spondylolisthesis, an L5-S1 anterior or posterior fusion and a malformation of the lumbosacral hinge were excluded. All measures were performed using CT-scan data on AW volume Shore 5 software (General Electric, Fairfield, Connecticut) and Carestream Vue PACS software (CarestreamHealth, Rochester, New York). Patients were installed in the supine position during the CT-scan acquisition. All measurements were bilateral and independently achieved on each pelvic CT-scan. Regarding lumbosacral disc degeneration, anterior and posterior osteophytes were not considered.

Anatomical study of the S1 sacral foramina

Before exiting from the first sacral hole, the S1 root passes through the S1 lateral recess and subsequently through the S1 foramen. The S1 root courses inferior to the S1 pedicle and anterior to the S1 vertebral body. In consequence, an IS screw with an ectopic direction may injure the S1 root.

The S1 lateral recess and S1 foramina were separately studied. Regarding the S1 lateral recess, the S1 lateral recess inlet area was measured in the plane of the sacral endplate and the S1 lateral recess outlet area and height were measured in the sagittal plane (Fig. 2). Regarding the S1 foramina, the areas of the anterior and posterior first sacral holes on CT-scan slides respectively tangent to the anterior and posterior sacral aspects were measured. On transverse slides perpendicular to the posterior aspect of the sacrum, the distance between the first posterior and anterior sacral holes corresponding to the sacral thickness was measured. On tridimensional reconstructions, in the plane tangent to the posterior sacral aspect, the distance between the base of the S1 superior articular facet and the top of the posterior first sacral hole was also evaluated (Fig. 3). To assess the S1 vertebral body, the sacral endplate thickness and the thickness of the inferior part of the S1 vertebral body were measured in the sagittal plane. The orientation of the S1 foramina in the sagittal, coronal and transverse planes was also studied (Fig. 4).

Description of the user guide of spino-pelvic fixation with IS screws

Two invariable landmarks were defined. The first point (point A) was in the sagittal plane at equidistance from the first posterior sacral hole and the base of the S1 superior articular facet; in the transverse plane, it was placed 10 mm perpendicular and

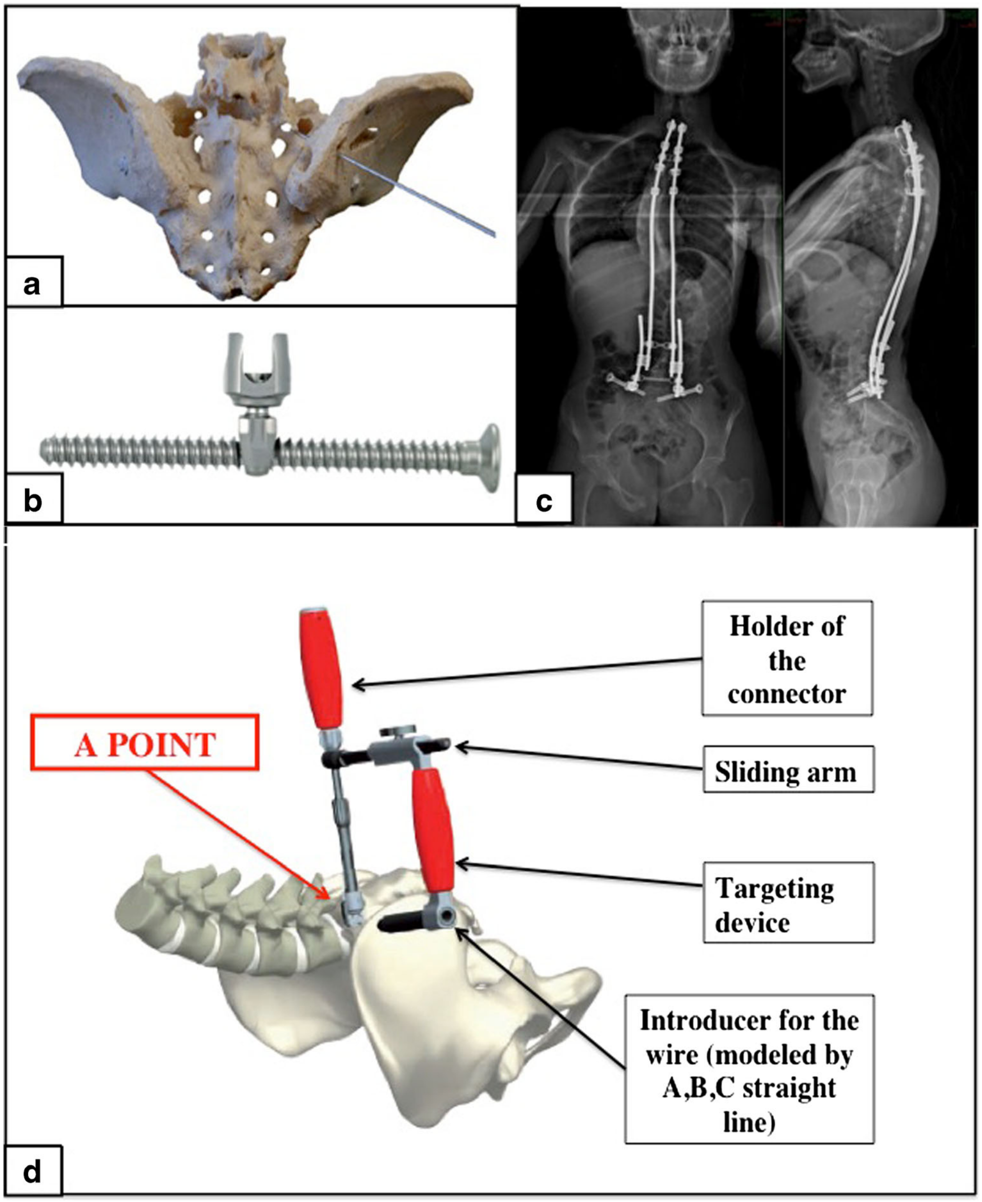

Fig. 1 Illustration of spino-pelvic fixation with IS screws. A threaded pin extends from the external aspect of the iliac wing to the S1 vertebral body and corresponds to the direction of the IS screw (iliosacral connector E-Spine EUROS, France) (**a**). The device of spino-pelvic fixation is composed of a cannulated IS screw and a polyaxial connector binding the screw to the spinal instrumentation rod (iliosacral connector E-Spine EUROS, France) (**b**). Anteroposterior and sagittal full spine X-rays illustrate the clinical application of this spino-pelvic fixation (**c**). Illustration of the ancillary allowing the positioning of the IS screw by percutaneous approach (**d**)

anterior to the posterior aspect of the sacrum. Point B was located at the junction of the anterior third and middle third of the S1 vertebral body right under the sacral endplate in the sagittal plane and at the middle of the endplate in the coronal plane. During the surgical procedure, following the exposure of the posterior aspect of the sacrum, the operator places the connector using a holder linking the IS screw with the rod of the spinal instrumentation. Point A corresponds to the position of the connector. The ancillary contains a targeting device attached to the connector holder for the insertion of a wire corresponding to the direction of the IS screw. The wire position is controlled by fluoroscopy to place the tip of the wire at the previously described point B (Fig. 1D). Points A and B allowed the operator to model the final direction of the IS screw (ABC straight line) and deduce the location of the third point (point C) (Fig. 5). Point C corresponded to the intersection between the A-B direction and the external cortex of the iliac wing. Point C always has to be located 1 cm under the iliac crest so that the head of the IS screw holds in the iliac wing and avoids being protruding under the skin. From this A-B-C straight line, modeling the placement of the IS screw, the direction in the sagittal, coronal and transverse planes was measured (Fig. 6).

Statistical analysis

Continuous data were described with mean and 95% confidence interval (CI). The effect of gender on the anatomy of the S1 sacral foramina and the placement of IS screw was processed using Student's t-test. The effect of age, height and weight was processed using a non-parametric Spearman

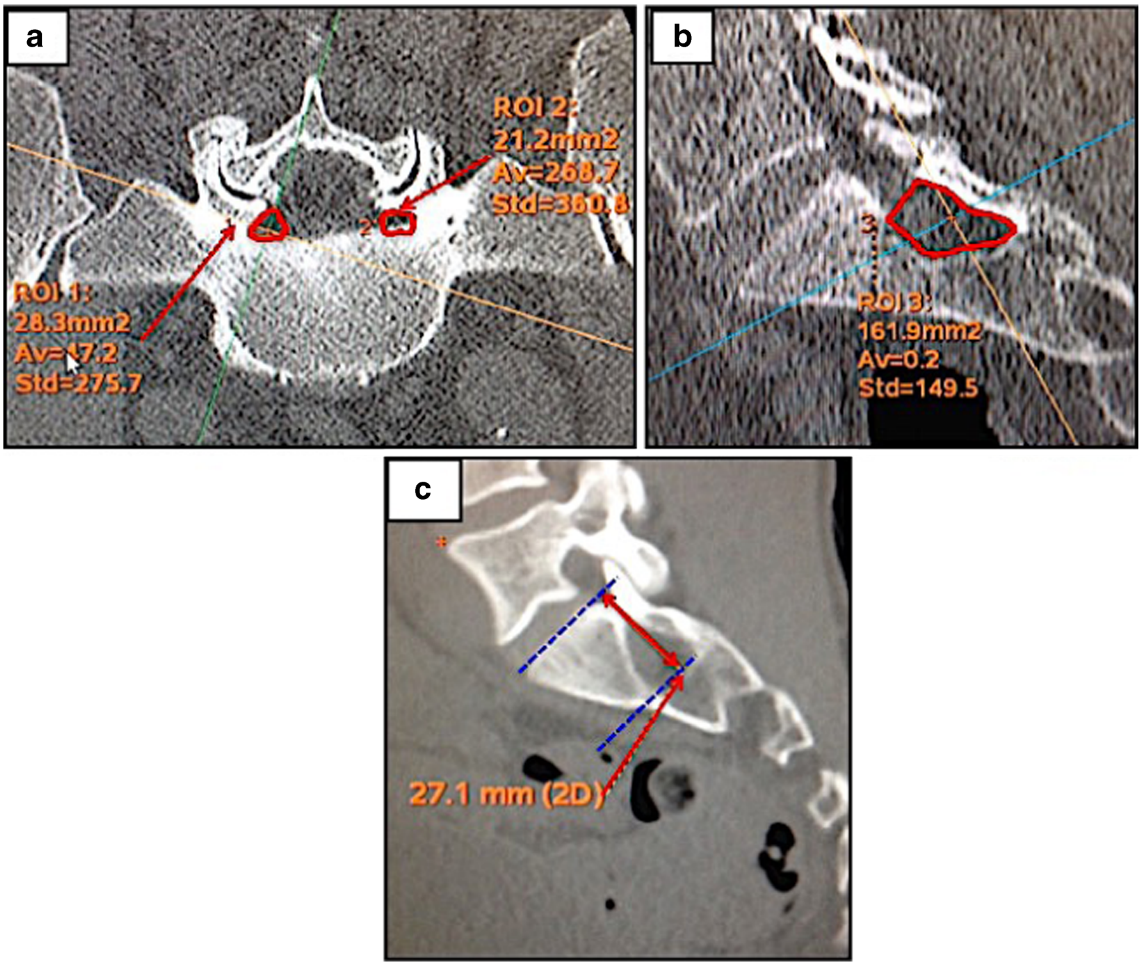

Fig. 2 S1 lateral recess measurements: area of the S1 lateral recess inlet (mm^2) delimited by a *red line* (**a**), area of the S1 lateral recess outlet (mm^2) delimited by a *red line* (**b**) and the S1 lateral recess height (mm) corresponding to the *red double arrow* between the *two blue lines* (**c**)

correlation analysis. Post hoc power analysis has been evaluated for each parameter.

$P < 0.05$ was considered statistically significant. Data were recorded in Excel® 2008 (Microsoft, Richmond, WA). All statistical analyses were performed using SPSS® Advanced Statistics 20.0 software (IBM, Armonk, NY).

Results

Anatomical study of the S1 foramina and S1 vertebral body (Tables 1 and 2)

The mean age was 53.1 years (95% CI [44.9–61.8]), 55.3 years (95% CI [47.8–62.1]) for female patients and 50.9 years (95% CI [42.2–59.3]) for male patients, respectively. The population was equally composed of 15 male patients and 15 female patients. Regarding the anatomical study of the S1 sacral hole, the S1 lateral recess inlet and S1 lateral recess outlet mean areas were, respectively, 25.4 mm^2 (95% CI [22.9–28.2]) and 193.2 mm^2 (95% CI [182.6–203.2]). The average S1 lateral recess height was 29 mm (95% CI [28–29.9]). The mean areas of the anterior and posterior first sacral holes were, respectively, 169.2 mm^2 (95% CI [157.2–180.2]) and 98.7 mm^2 (95% CI [89.6–107.4]). The mean distance between the anterior and posterior first sacral holes was 27.6 mm (95% CI [26.6–28.4]). The mean distance between the base of the S1 superior articular facet and the top of the first posterior sacral hole was 10.7 mm (95% CI [9.9–11.5]). Regarding the S1 vertebral body measurements, the sacral end plate and the inferior part of S1 vertebral body thicknesses were, respectively, 27 mm (95% CI [26.1–27.9]) and 18.1 mm (95% CI [17.3–18.9]). The S1 foramina were oriented 48° (95% CI [45.4–50.4]) anteriorly and outwardly in the transverse plane, 55.7° (95% CI [54.4–57.1]) anteriorly and downwardly in the sagittal plane, and 38.6° (95% CI [36–41.1]) downwardly and outwardly in the coronal plane.

Age had no effect on the anatomy of the upper sacrum. The S1 lateral recess outlet area slightly increased for male patients ($p = 0.04$) and was slightly correlated with height ($r = 0.5$; 95% CI [0.13–0.68]); $p = 0.03$). The area of the posterior first sacral holes was slightly correlated with height ($r = 0.4$; 95% CI [0.09–0.6]); $p = 0.01$). The first sacral hole's

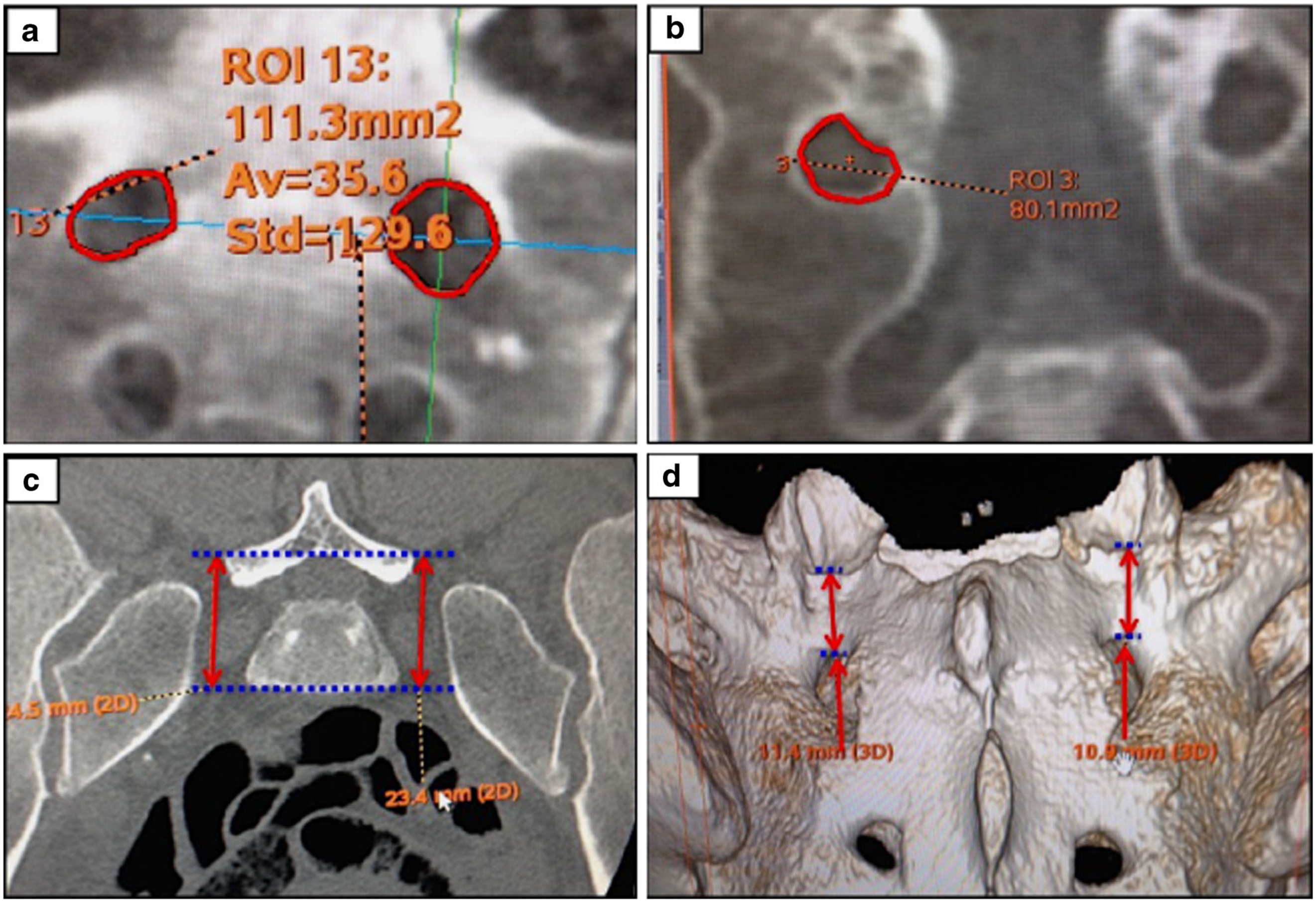

Fig. 3 S1 foramina measurements: first anterior sacral hole area (mm^2) delimited by a *red line* (**a**), first posterior sacral hole area (mm^2) delimited by a *red line* (**b**), distance between the anterior and posterior first sacral holes (mm) corresponding to the *red double arrow* between the *two blue lines* (**c**), distance between the basis of S1 superior articular facet and top of the first posterior sacral hole (mm) corresponding to the *red double arrow* between the *two blue lines* (**d**)

anteroposterior distance increased in male patients ($p = 0.001$) and was slightly correlated with height ($r = 0.4$; 95% CI [0.18–0.6]); $p = 0.007$). The distance between the base of the S1 superior articular facet and the top of the posterior first sacral hole was slightly correlated with height ($r = 0.3$; 95% CI [0.29–0.75]); $p < 0.001$) and correlated with weight ($r = 0.6$; 95% CI [0.6–0.9]); $p < 0.001$). Sacral end-plate thickness increased in male patients ($p < 0.001$) and was strongly correlated with height ($r = 0.6$; 95% CI [0.29–0.75]; $p < 0.001$) and weight ($r = 0.8$; 95% CI [0.6–0.9]; $p < 0.001$). The inferior part of the S1 vertebral body thickness increased in male patients ($p < 0.001$) and was slightly correlated with height ($r = 0.4$; 95% CI [0.14–0.63]; $p = 0.007$).

Assessment of the user guide of spino-pelvic fixation with IS screws (Table 3)

Using invariable points A and B, there was no misplaced screw and no penetration of the SI joint: all screws were placed posterior to the joint. According to this method, the screw direction was estimated at 55.5° (95% CI [53.2–58.1]) anteriorly and medially in the transverse plane, 17.9° (95% CI [13.4–22.4]) downward and medially in the coronal plane and 24.4° (95% CI [17.4–31.3]) downward and anteriorly in the sagittal plane. The mean IS screw length was 76.3 mm (95% CI [75–77.7]). Only gender influenced the screw direction with regards to the sagittal plane. No other studied variable influenced the placement of the IS screw using this method.

Discussion

The anatomical study of the S1 sacral foramina and the S1 vertebral body demonstrates the narrowness of this region demanding an accurate surgical technique. Previously, Templeman et al. [19] showed that an intra-operative error as minor as 4 degrees may direct IS screws either into the S1 foramina or through the anterior cortex of the sacrum. Despite the presence of a narrow bone corridor, the present study advocates that spino-pelvic fixation with IS screws is achievable and

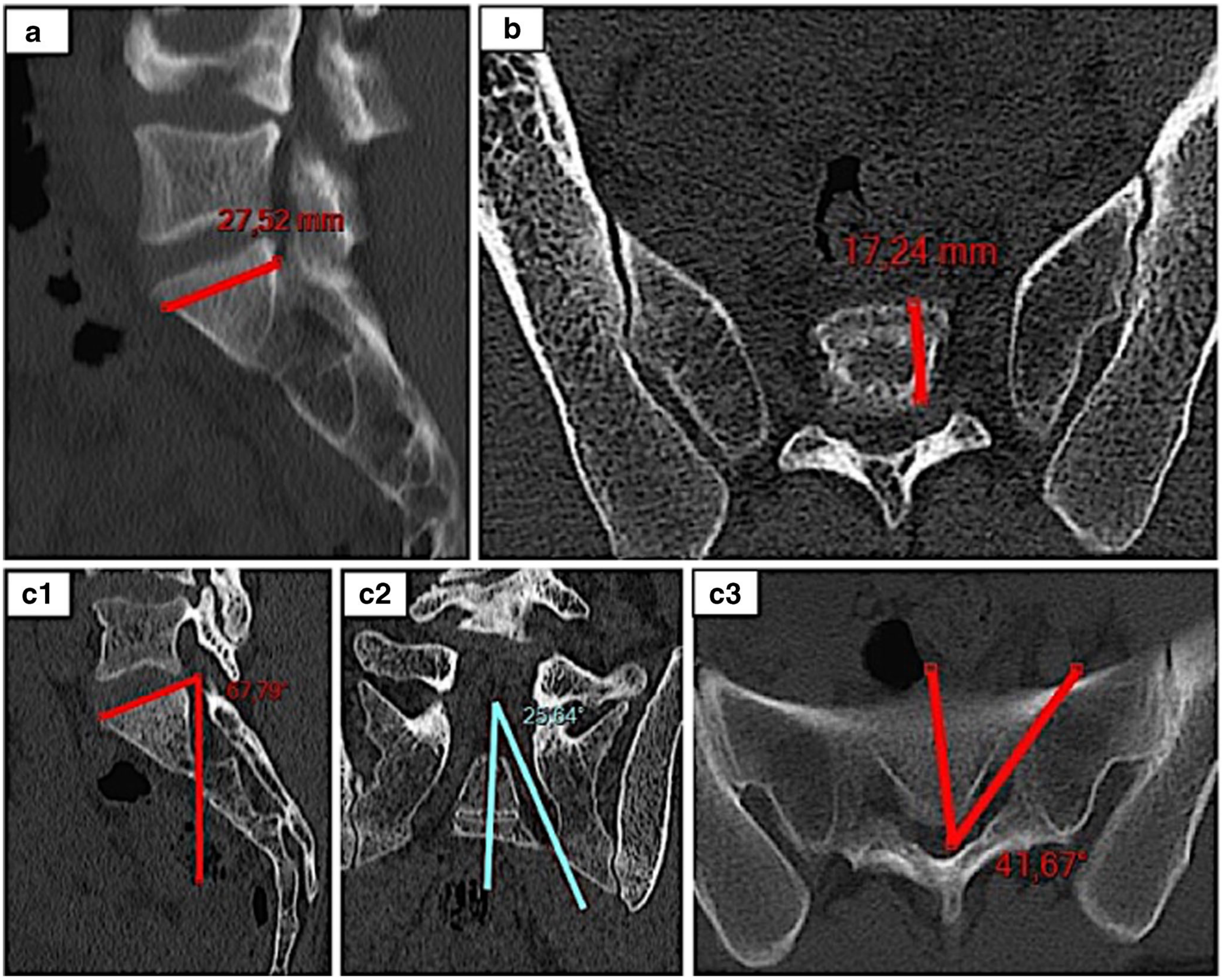

Fig. 4 S1 vertebral body measurements and orientation of the S1 foramina: thickness of the sacral end-plate (mm) modeled by a *red straight line* (**a**), thickness of the inferior part of S1 vertebral body modeled by a *red straight line* (mm) (**b**) and the orientation of the S1 foramina (degree) (sagittal direction (**c**1), coronal direction (**c**2) and transversal direction (**c**3))

reproducible in adult spinal surgery. In fact, this study highlights the relatively constant anatomy of the upper sacrum according to age, gender and morphologic characteristics, allowing the description of a reliable and fast technique of IS screw placement in the prone position. Except for the S1 body vertebral thickness, the majority of correlation coefficients are below 0.5. Ebraheim et al. [29] reported similar results: according to them, the measurements of male specimens were slightly larger than those from female specimens. Moreover, the totality of our measures had been performed on CT-scan; they consequently had a high precision of a tenth of a millimetre and a tenth of a degree, higher than other measurements achieved manually.

A common semantic confusion exists between the IS screw technique which bridges the sacroiliac joint ending into the contralateral ala of the sacrum or the S1 body for fixation of pelvic ring fractures as it was first described by Matta et al. [11, 32] and the IS screw which passes posterior and cephalad to the sacroiliac joint ending in the S1 body, described by Dubousset et al. [12] as a pelvic anchor for long spinal instrumentations. In the present study, only the latter technique was assessed. Indeed, they have little in common. The technique described by Matta et al. [11, 32] and Routt et al. [10] later described a percutaneous technique using cannulated lag screws on patients respectively lying in the prone and the supine positions. In this case, the IS screw crosses the injured sacroiliac joint. This type of fixation was not intended to prolong or to strengthen spinopelvic instrumentations. However, the technique described by Dubousset [12] was performed on patients lying in the prone position and has not changed since. In this case, the IS screw does not cross the sacroiliac joint but courses behind the joint and spares it. Further developments included the design of an ancillary and improvements of the connector that simplified the technique for less experienced surgeons (iliosacral connector E-Spine EUROS, France) (Fig. 1).

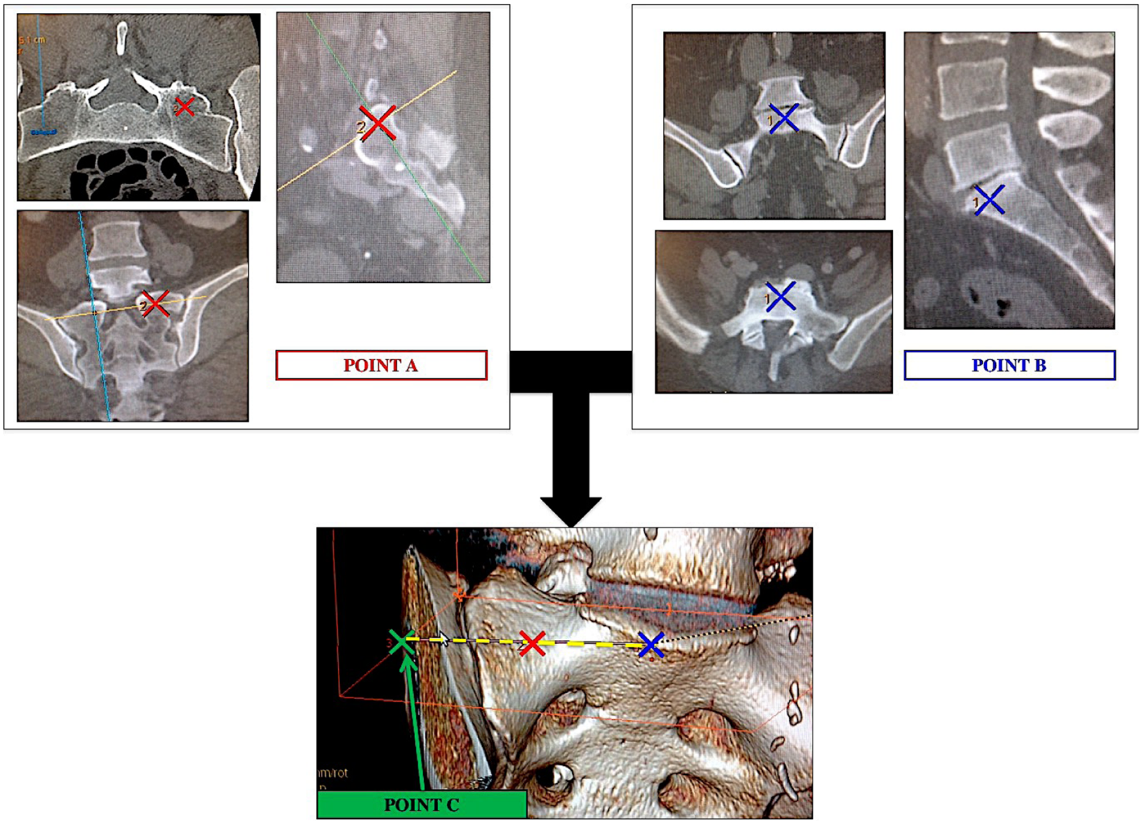

Fig. 5 Illustration of the two landmarks A (*red cross*) and B (*blue cross*) in the 3 different planes. *Points A* and *B* allow modeling the IS screw direction and deducing *point C* (*green cross*). *Landmark C* is located onto the external aspect of the iliac wing

The osseous tunnel crossed by the screw in both techniques varies, as well as the entry point and direction. While the entry point of the iliosacral screw on the external aspect of the iliac bone is strictly fixed for pelvic ring trauma (lateral X-ray using fluoroscopy or surgical navigation are mandatory), its location or point C in the present study is variable. A dedicated ancillary now guides the entry point in the latter technique.

Regarding the optimal placement of the iliosacral screw, according to Routt et al. [10] the percutaneous technique in the supine position for pelvic ring fractures imposes a direction perpendicular to and across the SI joint (or sacral fracture), through the sacral ala, cephalad to the S1 neural foramina, caudad to the L5/S1 disc space, and terminating within the body of S1 or the contralateral sacral ala. According to the technique described by Dubousset et al. [12], the IS screw has a variable entry point on the external cortex of the iliac bone, passes posterior and cephalad to the sacroiliac joint and through a connector 10 mm embedded in a curetted hole at the base of the S1 superior articular process, runs caudal and parallel to the L5/S1 disc space and ends with a tip ideally located at the center of the S1 body. Knowing the distinctive characteristics of these two techniques bearing the same name, one may notice that to this date, no cadaveric study has assessed the reliability and reproducibility of the IS screw placement as described by Dubousset

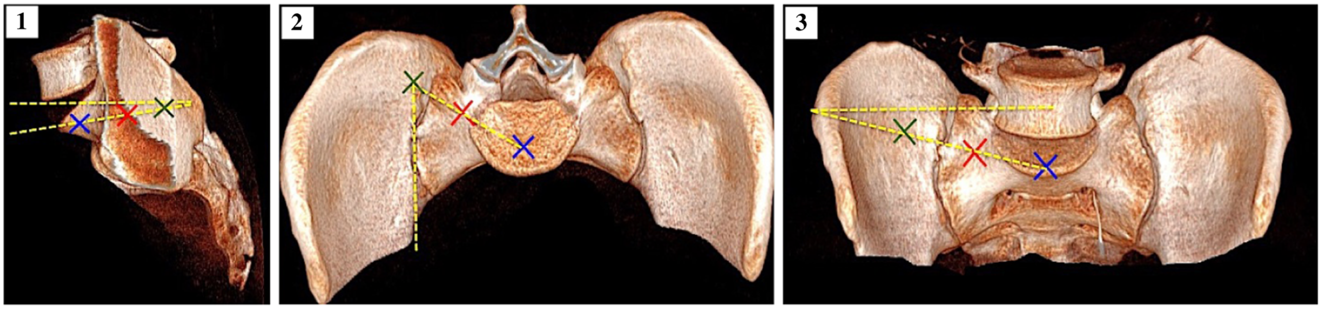

Fig. 6 Tridimensional measurement of the “ideal” IS screw placement using *points A* (*red cross*), *B* (*blue cross*) and *C* (*green cross*). The “ideal” IS screw direction was modeled by the ABC straight line in the sagittal plane (1), the transversal plane (2) and coronal plane (3)

Table 1 Anatomical study results of S1 sacral foramina

Data measured	Values (n = 30) (95% CI)	Female patients (N = 15) (95% CI)	Male Patients (N = 15) (95% CI)	p-value	Post hoc power analysis (%)
Age (years)	53.1 (44.9–61.8)	55.3 (47.8–62.1)	50.9 (42.2–59.3)	0.5	/
Weight (kg)	70.2 (59.8–80.1)	57.5 (48.7–68.9)	80.3 (72.5–87.8)	0.001	/
Height (cm)	167.7 (162.3–173.2)	158.8 (155.3–162)	174.8 (170.9–178.8)	<0.001	/
S1 lateral recess measurements					
S1 lateral recess inlet area (mm^2)	25.4 (22.9–28.2)	24.8 (21.5–28.1)	26 (21.8–30.2)	0.6	100
S1 lateral recess outlet area (mm^2)	193.2 (182.6–203.2)	182.4 (169–196.5)	204 (188.9–218.5)	0.04	99.9
S1 lateral recess height (mm)	29 (28–29.9)	28.4 (26.7–29.8)	29.6 (28.5–30.8)	0.2	100
S1 foramina measurements					
Anterior first sacral hole area (mm^2)	169.2 (157.2–180.2)	167.5 (150–185.6)	171 (154.8–185)	0.8	99.2
Posterior first sacral hole area (mm^2)	98.7 (89.6–107.4)	93.9 (79.7–109.7)	103.4 (93–113.8)	0.3	98.2
First sacral holes anteroposterior distance (mm)	27.6 (26.6–28.4)	26.1 (25.1–27)	29.1 (27.8–30.4)	0.001	100
Distance between the S1 superior articular facet and the top of the first posterior sacral hole (mm)	10.7 (9.9–11.5)	10 (9.1–10.8)	11.5 (10.2–12.7)	0.07	99
S1 vertebral body measurements					
Sacral end-plate thickness (mm)	27 (26.1–27.9)	24.9 (23.9–26)	29.2 (28–30.3)	<0.001	100
Inferior part of S1 vertebral body thickness (mm)	18.1 (17.3–18.9)	16.6 (15.6–17.6)	19.5 (18.5–20.6)	<0.001	100
Orientation of the S1 foramina					
- Transversal (°)	48 (45.4–50.4)	46.7 (42.3–50.8)	49.4 (46.6–52)	0.3	100
- Coronal (°)	38.6 (36–41.1)	36.2 (32.1–40.8)	40.9 (38.4–43.5)	0.07	100
- Sagittal (°)	55.7 (54.4–57.1)	57.5 (55.8–59.5)	53.9 (52.2–55.8)	0.01	100

et al. [12]. This present work aims to provide accurate landmarks and a practical radiographic user guide for further studies aiming to confirm these data with surgeons in the setting of cadaveric simulations or clinical trials.

The percutaneous placement of the IS screw is the other advantage of this spino-pelvic fixation [7]. Initially, surgeons had to expose the outer iliac cortex to introduce the IS screw, and the Beurier connector was positioned in the IS space as described by Farcy et al. [3]. The development of new percutaneous ancillaries allows a safer placement of the IS screw in the prone position without dissecting the IS region. This possibility of minimally invasive surgery could reduce the risk of peri-operative complications like surgical-site infections [33]. It is not necessary to expose the external iliac wing because the entry point (point C) of the IS screw at the level of the external aspect of the iliac bone is a variable point. To achieve a correct placement, the direction of the IS screw has to pass through the invariable points A and B as previously described in the present study. In fact, point A corresponds to the position of the connector between the IS screw and the spinal instrumentation next to the entry point of the S1 pedicular screw. Point A is exposed during the surgical approach and navigation or fluoroscopy is not necessary to locate it. Point B is positioned under the junction of the middle third and anterior third of the sacral endplate representing the densest trabecular bone of the sacrum as demonstrated by Peretz et al. [20, 21]. Point B can be located either by a simple lateral X-ray on fluoroscopy or by surgical navigation. Subsequently, point C is deduced from both precedent points and exposed by percutaneous approach. Thus, we preferred to describe the optimal screw direction according to the conventional tridimensional planes and not according to the posterior sacral aspect as extensive sacral exposure is not necessary for this percutaneous technique.

Some authors advocated that IS screw fixation is a strong fixation bringing equivalent stability in comparison with other pelvic fixations [34, 35]. Important stability of this fixation depends on four factors. The first factor is the tricortical bone anchorage (external and internal cortical iliac bones, posterior cortex of the sacrum) preventing screw pullout and instrumentation failure [3]. The second factor is the placement of the screw throughout dense trabecular bone just below the sacral endplate and the sacral promontory [21]. The third factor is the transverse position of the screw leading to a load sharing effect of the hardware increasing the resistance against superior pull-out forces related to the spinal instrumentation. This screw merges with the rotational axis of the SI joint constituting the fourth factor of stability. This screw preserves the SI joint since it does not bridge it and spares its motion.

Even though pelvic fixation with IS screws seems to be interesting in adult spinal deformity, long-term prospective studies are mandatory to completely validate this surgical method. Only two studies retrospectively assessed this sacro-pelvic fixation in adult spinal surgery [3, 14]. Farcy et al. [3] retrospectively analyzed 28 consecutive patients with this pelvic fixation. After a mean follow-up of 3.5 years, no neurologic complications were observed and 95% of the patients had radiographic evidence of fusion. Furthermore, among these 28 included patients, 23 presented with pseudarthrosis following previous surgery showing that IS screw fixation could be an

Table 2 Analysis of anatomical variations of the upper sacrum according to age, height and weight

Variables	Age	Height	Weight
S1 lateral recess measurements			
S1 lateral recess inlet area	NS	NS	NS
S1 lateral recess outlet area	NS	$r = 0.5$ 95% CI (0.2–0.7) $p = 0.03$	NS
S1 lateral recess height	NS	NS	NS
S1 foramina measurements			
Anterior first sacral hole area	NS	NS	NS
Posterior first sacral hole area	NS	$r = 0.4$ 95% CI (0.09–0.6) $p = 0.01$	NS
Anteroposterior diameter of the first sacral holes	NS	$r = 0.4$ 95% CI (0.18–0.6) $p = 0.007$	NS
Distance between the S1 superior articular facet and the top of the posterior first sacral hole	NS	$r = 0.3$ 95% CI (0.03–0.6) $p = 0.03$	$r = 0.6$ 95% CI (0.3–0.8) $p < 0.001$
S1 vertebral body measurements			
Sacral end-plate thickness	NS	$r = 0.6$ 95% CI (0.29–0.75) $p < 0.001$	$r = 0.8$ 95% CI (0.6–0.9) $p < 0.001$
Inferior part of S1 vertebral body thickness	NS	$r = 0.4$ 95% CI (0.14–0.63) $p = 0.007$	NS
Orientation of the S1 foramina			
Sagittal	NS	NS	NS
Coronal	NS	NS	NS
Transversal	NS	NS	NS

NS non significant, *CI* confidence interval, *r* correlation coefficient

alternative in case of failure of other spino-pelvic fixations. Ould-Slimane et al. [14] analyzed radiographic outcomes of sacro-pelvic fixation with ilioscral screws after a two-year follow-up. No mechanical complication was reported and lumbopelvic correction was performed in all cases.

Assessment in the supine position could be considered as a measurement bias in the present study. In fact, during the surgical procedure, pelvic fixation and posterior spinal instrumentation are performed in the prone position and this difference may modify these measurements. However, we

Table 3 "Ideal" IS screw placement results

Data measured	Values ($n = 10$) (95% CI)	Female patients (N = 5) (95% CI)	Male patients (N = 5) (95% CI)	p-value	Post hoc power analysis
Age (years)	63.7 (57.1–70.1)	67 (59.8–74.7)	60.4 (49–72.5)	0.5	/
Weight (kg)	68.4 (61.2–75.9)	65.8 (54.5–80.4)	71.8 (67.2–76.8)	0.005	/
Height (cm)	165.7 (160.8–170.1)	159.8 (153.8–166.3)	173 (170.5–176)	0.004	/
Optimal direction and iliosacral screw mean length					
Transversal (°)	55.5 (53.2–58.1)	57.8 (54.9–61.3)	53.2 (49.7–56.7)	0.08	75
Coronal (°)	17.9 (13.4–22.4)	17 ± (7.9–25.9)	18.8 (15.6–23)	0.7	81.8
Sagittal (°)	24.4 (17.4–31.3)	15.9 (6–27)	32.9 (26.2–38.9)	0.02	100
Length (mm)	76.3 (75–77.7)	75.7 (74.1–77.4)	76.9 (74.5–79.1°	0.4	35.1

considered this difference of measurement negligible because the rotary motion of SI joints is usually inferior to 4° and decreases with age [36, 37]. Furthermore, the respective positions of points A and B are invariable and consequently do not change according to the supine or prone position. Finally, most parameters were measured from intrinsic landmarks. Such landmarks do not change according to patient position.

Spino-pelvic fixation using IS screws is one option among the numerous types of described lumbosacral fixations. This computed tomographic simulation advocates the interest of this new user guide of pelvic fixation with IS screw but it must be clinically evaluated to completely consider this user guide as reliable and reproducible. With sufficient knowledge of this percutaneous surgical procedure, it is possible without navigation to correctly place IS screws in the prone position despite the proximity of the S1 sacral foramina and the presence of a narrow bone corridor that remains relatively constant independent of age, gender and patient morphologic characteristics.

Compliance with ethical standards

Conflict of interest No author received any financial support that might pose a conflict of interest in connection with the submitted article. No author or any member of his or her immediate family, has no funding or commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

I agree and confirm this statement as true.

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