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Standardized Posterior Pelvic Imaging: Use of CT Inlet and CT Outlet for Evaluation and Management of Pelvic Ring Injuries

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Abstract

Objectives—The null hypothesis of the current study states that routine axial CT images are obtained at a consistent and reproducible orientation relative to the sacrum. The secondary null hypothesis states that there is no difference in the measurement of the safe zone for placement of iliosacral screws when using routine axial CT images and standardized reconstructions in defined planes perpendicular and parallel to the sacrum.

Design—Retrospective review.

Setting—University Level-1 Trauma Center

Patients—Sixty-eight consecutive trauma patients evaluated with routine pelvic computed tomography, without pelvic ring injury.

Intervention—Retrospective radiographic review and measurement.

Methods—Sixty-eight consecutive adult patients with routine axial pelvic CT scans, without injury to the pelvic ring and obtained as part of a trauma evaluation were retrospectively identified. The orientation of the axial slices relative to the sacrum was measured for each patient and compared. The maximal cross-sectional distance at the smallest section of the sacral ala (safe zone) was measured using the routine axial CT images and these measurements compared to similar measurements taken on standardized images perpendicular (CT Inlet) and parallel (CT Outlet) to the body of the sacrum. Additional data referencing the orientation of multiple sacral radiographic landmarks were also collected.

Results—The orientation of routine axial CT image planes relative to the sacrum spanned a wide range. The angle between the routine axial CT plane and the sacrum varied from 43.5 degrees to 82.0 degrees (SD = 9 degrees). Significant differences were found in measured safe zones of routine axial CT images compared to standardized CT Inlet and CT Outlet images. Compared to

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CT Inlet images, routine axial CT images underestimated safe zones for transverse sacral screws at both S1 ($p<0.01$) and S2 ($p<0.01$). When compared to CT Outlet images, routine axial CT images overestimated safe zones for oblique sacro-iliac screws ($p<0.01$), and underestimated the safe zone for S2 transverse sacral style screws ($p<0.01$). No significant differences in measured variables were found between genders and sacral morphology.

Conclusions—Our null hypotheses were rejected: routine axial CT images were found to be at widely ranging orientations relative to the sacrum, and standardized CT images (CT Inlet and CT Outlet) demonstrated statistically significant differences in measurements of safe zones compared to routine axial CT images. Furthermore, the CT Inlet and CT Outlet views provide additional information regarding sacral landmarks that could be useful for pre-operative planning.

Keywords

Pelvis; Pelvic Ring Injury; Computed Tomography

INTRODUCTION

Recent studies have shown the anatomic safety^[1] and operative outcomes^[2-5] of complex fixation strategies through the upper and second sacral segments. The safety and efficacy of these strategies relies on the surgeon's pre-operative evaluation of each patient's sacral anatomy and its intra-operative fluoroscopic representation. Routine axial CT images are used for this purpose, but their utility may be limited because the CT image planes are created in reference to the supine patient with the gantry orthogonal to the CT table. Given the variability in lumbar lordosis and pelvic tilt between individuals, routine axial CT imaging protocols are likely to result in non-standard oblique cuts through the pertinent posterior pelvic ring osseous structures.

The primary purpose of the study was to evaluate the orientation of routine CT scans relative to the sacrum and to evaluate the information available for pre-operative planning using these routine axial pelvis CT scans compared to standardized CT scan images oriented perpendicular to the sacrum (CT Inlet) and parallel to the sacrum (CT Outlet). Specifically, measurement of the safe zone for placement of iliosacral screws was undertaken using the CT Inlet and CT Outlet images and compared to those taken with routine axial CT images. The null hypotheses were that routine axial CT images are made at a reproducible orientation relative to the sacrum and that routine axial CT measurement of the safe zone for application of iliosacral screws is similar when compared to those in standardized images perpendicular and parallel to the body of the sacrum.

METHODS

Patients

Sixty-eight consecutive trauma patients (44 males and 24 females with an average age of 40 years; range, 18 to 92 years) admitted to a single level-I trauma center who had routine pelvic CT examinations without pelvic ring injury were identified retrospectively. Their plain radiographs were used to classify each sacrum as either dysmorphic (25 patients) or normal (43 patients), on the basis of previously published criteria.^[6]

Evaluation of Routine Axial CT Plane and Neuroforamen Orientation

Routine axial CT orientation was measured as the angle between a parallel to the CT gantry and the midline tangent to the anterior S1 body (Figure 1). The sacral midline was determined as the line connecting the midpoint between the neuroforamen and the tip of the spinous process. Because of the variable sagittal plane orientation of the cranial two sacral segments and the trapezoidal shapes of the sacral vertebral bodies, multiple planes of reference were created including midline tangents to the anterior and posterior S1 and S2 bodies, as well as the mid body plane defined by the bisector of the anterior and posterior S1 and S2 body tangents (Figure 2). The sagittal orientation of the S1 neuroforamen were defined using paramedian sagittal reconstructions to measure the angle between the routine axial CT plane and the angle of each S1 neuroforamen (Figure 3). Right and left side values for each patient were averaged for statistical analyses.

CT Outlet and CT Inlet planes

Standardized CT Inlet and CT Outlet images were created perpendicular and parallel to the sacrum, respectively. To accomplish this, a real-time, computer-generated reformatting program (version 5.30.8.30 EVMS [Enterprise Visual Medical System] Advanced Visualization; Emageon, Birmingham, Alabama) that is routinely available to all hospital personnel at our institution was used to manipulate the routine CT image data to produce reformatted images in standardized planes. Tangents to the sagittal midline anterior and posterior sacral bodies of S1 and S2 segments were determined.^[7] The bisectors of these tangents were used to define the plane parallel to the sacrum. This plane was used to create the CT Outlet images used to measure the “height” of each segments’ safe zone (Figure 4). A perpendicular to these bisectors defined the planes of the CT Inlet images used to measure the “depth” of each segment's safe zone (Figure 5).

Screw Trajectories

Screw trajectories to mimic an “ideal” trans-sacral style screw and an “ideal” sacro-iliac style screw^[8] were defined using the images in each plane. Trans-sacral style screws were oriented transversely across the sacrum, parallel to a line drawn connecting the posterior iliac crests seen on each CT image (Figure 6a). Sacroiliac style screw trajectories were oriented in line with the major axis of the sacral ala on each side. The trajectory was chosen that would maximize the surrounding bone in the ala throughout its course, with the screw path directly down the middle (Figure 6b). Angles of insertion of “ideal” sacro-iliac style screws were recorded in the routine axial, CT Inlet, and CT Outlet planes.

Evaluation of Safe Zones

After choosing the CT image that displayed the maximal safe zone for transverse and oblique iliosacral screws in the routine axial, CT Inlet, and CT Outlet planes, the distances were measured between the limiting osseous borders. Parallel lines to the posterior iliac crest reference were drawn across the sacrum at the cranial/anterior and caudal/posterior borders of the sacrum and a perpendicular distance was measured in each plane (Figure 7). Measurement of the safe zone for sacro-iliac style screws was performed using a

perpendicular line to the proposed “ideal” trajectory at each ala's smallest portion, in each plane (Figure 8).

Comparisons and Statistical Evaluations

Measurements of the entire cohort were performed by a single attending surgeon who specializes in orthopaedic traumatology. Variation between the anterior body of S1, the routine axial CT plane and the neuroforaminal angles were evaluated using means and standard deviations, with the potential effects of gender and dysmorphism evaluated with unpaired Student's t-test. The idealized screw trajectory angles and distances measured for both the CT Inlet and CT Outlet planes were compared with those of the standard CT axial plane with use of the paired Student's t-test. A p-value of <0.05 was defined as significant.

The reproducibility of the measurement methods utilized was tested using a representative sample of 10 subjects based on gender and dysmorphism. A second attending orthopaedic traumatologist established the CT Inlet and Outlet planes and measures safe zones. Angular and safe zone measurement data was aggregated and compared. Intraclass correlation (ICC) was estimated between the two observers using a twoway, mixed effects model with both an absolute agreement and consistency definition. According to guidelines proposed by Landis and Koch[9], an ICC value of less than 0 indicates no agreement, 0–0.20 indicates slight agreement, 0.21–0.40 indicates fair agreement, 0.41–0.60 indicates moderate agreement, 0.61–0.80 indicates substantial agreement, and 0.81–1 indicates almost perfect agreement.

RESULTS

Routine Axial CT and Neuroforamen Orientation

Routine axial CT images were found to have a wide range (43.5–82.0 degrees) in their orientation relative to the sacrum. The mean difference in the orientation of routine axial CT image plane and the tangent to the anterior body of S1 was 21 degrees with a standard deviation of 9 degrees. The distribution of the sacral axis angles is displayed in Figure 9. The distribution is approximately symmetric (skew = 0.164) and the kurtosis is not significantly different than that of a standard normal distribution (excess kurtosis = -0.223 , SE kurtosis = 0.574, $p>0.05$). These values were not significantly different ($p=0.72$) between males (mean=21.5, SD=9.4) and females (mean=20.7, SD=8.0), and not significantly different ($p=0.27$) between patients with dysmorphic (mean=22.8, SD=9.2) and normal (mean=20.3, SD=8.6) sacral anatomy. The mean angle between the neuroforamen and the routine axial CT plane was 55.7 degrees (SD=8.0, range 40.0–80.0 degrees). The average difference in the sagittal neuroforamen orientation relative to the S1 body was 13 degrees with a standard deviation of 7 degrees. These values were not significantly different ($p=0.60$) between males (mean=12.8, SD=7.7) and females (mean=13.8, SD=7.4), and not significantly different ($p=0.55$) between patients with dysmorphic (mean=13.9, SD=7.9) and normal (mean=12.7, SD=7.4) sacral anatomy (Table 1).

Screw Trajectories

Table 2 shows the determined angles of insertion for “ideal” sacro-iliac type screws (Figure 8) into the S1 body. Differences in insertion angle between normal and dysmorphic sacra

were analyzed. As expected, there was an increase in the angle away from the transverse reference in dysmorphic sacra compared to normal sacra using routine axial, CT Inlet, and CT outlet images bilaterally. The increase in angle of screw insertion between normal and dysmorphic sacra reached statistical significance bilaterally when measured on routine CT images ($p<0.05$) and CT Outlet images ($p<0.01$), resulting from more caudal/cranial obliquity than posterior/anterior obliquity to accommodate dysmorphic upper sacral anatomy.

Measured Safe Zones

Routine axial CT images provide inconsistent safe zone measurements compared to CT Inlet and CT Outlet images. Table 3 shows values for the measured safe zone distances for trans-sacral style screws in S1 and S2, and sacro-iliac style screws in S1. The mean safe zone for S1 trans-sacral style screw placement on routine axial images was 8.95mm compared with 14.40mm for CT inlet images and 8.96mm for CT outlet images. For S2, the values were 9.36mm, 11.39mm, and 9.94mm for routine axial, CT inlet and CT outlet images, respectively. Compared to CT inlet images, routine axial CT images underestimated the safe zone for application of a trans-sacral style screw in both S1 and S2 ($p<0.01$ for S1, $p<0.01$ for S2). Compared to CT outlet images, routine axial images underestimated the safe zone for application of a trans-sacral style screw into the S2 segment with statistical significance ($p<0.01$), although the difference was very small (0.58mm). There was no significant difference at S1 between routine axial CT measurements and CT Outlet measurements.

The combined mean of right and left safe zone measurements for sacro-iliac style screws into the right and left S1 segments was 17.42mm on routine axial CT images. Mean values for corresponding measurements using CT Inlet and CT Outlet images are shown in Table 3. There was no significant difference in the measured safe zone for the idealized S1 sacro-iliac style screws between routine axial and CT Inlet images. The difference between mean S1 safe zone distances measured on routine axial and CT Outlet was statistically significant ($p<0.01$), with routine axial CT images overestimating the safe zone by 1.00mm.

Interobserver reliability

Comparisons of the data collected by the two orthopaedic traumatologists are summarized in Table 4. Using standard criteria, very high agreement was seen in angular measures of the S1 bisectors (ICC = 0.82) for creation of the CT Inlet and CT Outlet planes. Very high agreement was also seen in measurements of the safe zone for S1 trans-sacral style screws in routine axial (ICC = 0.93), CT Inlet (ICC = 0.92), and CT Outlet (ICC = 0.91). Very high agreement was also seen in measurements of S1 sacro-iliac style screws, using the CT Outlet plane. All other values fell within the standards of “substantial” (0.61-0.80) or “moderate” (0.41-0.60) agreement.

DISCUSSION

Evaluation and management of unstable pelvic ring injuries is dependent on plain radiographic and CT imaging. In particular, critical evaluation of the posterior pelvic ring is necessary to diagnose an unstable injury and plan treatment. As we have shown, the plane of

routine axial CT imaging is not standard relative to the sacrum, with a wide range of almost 40 degrees of angulation (43.5-82.0 degrees). Accepting such variation is inconsistent with basic tenets of musculoskeletal imaging, where orthogonal views are standard. We, therefore, describe CT Inlet and CT Outlet images created by reformatting CT data that standardize CT evaluation of the posterior pelvis.

Related to the unique geometry of the sacral ala, changes in cross-sectional orientation of CT images were found to result in significant changes in distances measured to estimate the safe zone for application of iliosacral screws. Overestimation may lead the treating surgeon to choose a more risky iliosacral screw fixation approach, while underestimation may lead to pursuit of an alternate fixation strategy that is more invasive and may be associated with greater morbidity. Based on our results, routine CT images underestimate the space available for trans-sacral style screw placement into S1 compared to CT Inlet image measurement, and underestimate the space for a similar screw into S2 compared to both CT Inlet and CT Outlet image measurement. Routine CT images overestimate the safe zone for application of oblique, sacro-iliac style screws with statistical significance, but these small differences may not be clinically significant.

Multiple studies have used CT imaging to measure the safe zone for application of internal fixation.[1, 10-13] Four of these studies[1, 10, 12, 13] used multiplanar reformatting or standardized positioning of cadaveric specimens to orient the images to the long axis of the sacrum; however, none quantified the difference between their data and similar measurements that would be obtained clinically on routine axial CT images.

Ebraheim, et al.,[10] used cadaveric specimens to compare direct measurement, fluoroscopic measurement, and CT measurement of the safe zone of S1, focusing on the possibility of placement of two screws into this single sacral segment, and identifying a universal iliac starting point. Their results suggest that radiographic measurement underestimates gross anatomic measurement, but variation in measurement according to orientation was not specifically addressed. Noojin, et al., [11] measured the cross-sectional area of the sacral ala in 13 patients with uninjured pelves using CT reformatting in a plane parallel to the sacroiliac joint. They concluded that the smallest area for placement of screws was directly cephalad to the S1 foramen, and that all of their patients demonstrated adequate space for safe placement of two screws into the S1 body. They did not comment of the applicability of their imaging technique for pre-operative planning. Data from these studies are limited to the application of only oblique screws into the upper sacral segment, but are consistent with the findings in the present study regarding the potential for misinterpretation of a safe zone based on radiographic projection and the location of the greatest risk in the sacral ala.

Carlson, et al.[12] used the CT images of 30 healthy volunteers reformatted in a plane parallel to the superior endplate of S1 to characterize a three dimensional space through which screws of different trajectories could be placed, and then commented on their relative safety. Variation in anatomy between individuals was characterized based on the ability to place a transverse screw into S1 safely. Our data corroborate the high variability in anatomy amongst patients as we had similar results regarding the safe application of transverse screws. Day, et al.[13] used CT images of cadaveric specimens standardized in “inlet,”

“outlet,” and “oblique-sagittal” planes to evaluate screws placed into S1 with either a standard fluoroscopic technique or a novel computer assisted technique. Cortical perforation occurred twice in both groups. No comment was made on the utility of standardizing the CT images in reference to the sacrum compared to routine axial CT images. However, the use of reformatting similar to what is described in the current manuscript was suggested for confirmation of post-implant location.

Finally, Gardner, et al.[1] used sagittal reconstructions in their analysis of 50 patients’ CT scans to evaluate adequate space available for upper and second sacral segment screw fixation. Despite slight differences in technique for creating standardized views, our findings were very similar, including similar mean measurements of the “transverse safe zone” in normal and dysmorphic upper sacral segments

Safe use of iliosacral screw fixation, especially after closed manipulative reduction, relies on thorough anatomic understanding, detailed pre-operative planning, and intra-operative fluoroscopic guidance. Advancing technology makes evaluation of CT data in multiple planes directly available to the surgeon (Figure 10a-f). The use of reformatted CT data in multiple planes can allow the surgeon to more confidently discern between patients whose anatomy allows for safe use of iliosacral screws and provide the benefit of a lower morbidity approach (Figure 10g-i). Pre-operative planning with standardized and calibrated CT images also allows for measurement of safe zones in multiple trajectories through multiple sacral segments. Standardized for each individual patient, CT Inlet and CT Outlet images provide a tool for pre-operative planning, with which choice of implants and instruments can be predicted, and the appropriate diameter and length of instruments and screws can be confirmed and prepared. Further, expected angles for fluoroscopic inlet and outlet views can be predicted and communicated to the radiographic technician. .

Our study is subject to multiple limitations. We describe a technique that uses software that may not be readily available to surgeons at other institutions for real-time reformatting of CT imaging data. Furthermore, our technique is one of multiple techniques of multiplanar reconstruction in relation to the posterior pelvis and sacrum that have been described. While we acknowledge that there are many potential reference planes to use when evaluating pelvic ring injuries on CT, we believe that the strength of this study is not in which planes we chose for evaluation, but that a plane or planes were chosen in direct reference to the sacrum to avoid the variation in measurement that we illustrated when using planes that have no reproducible orientation to the sacrum. Another limitation is inherent in attempts to translate CT based information to operating room utility using fluoroscopy. We identified reference angles that would, theoretically, profile posterior landmarks with better reliability. However, in certain patients, these extreme outlet angles would not be feasible using a fluoroscopic unit in the operating room. Further study of the clinical application of some of these concepts is necessary to comment on their proposed clinical utility.

Use of CT Inlet and CT Outlet images allows the surgeon to make more accurate and thorough pre-operative plans based on images that more closely represent fluoroscopic images that will be used intraoperatively (Figure 10d-e). We have demonstrated that routine CT imaging does not produce standardized images of the pertinent posterior pelvic anatomy

due to the range of sacral orientation relative to the body in our sample. We believe that lack of standardized imaging may effect judgment in both clinical and research applications, and recommend the use of standardized CT images reformatted in relation to the sacrum to evaluate patients with pelvic ring injuries.

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REFERENCES

1. Gardner MJ, Morshed S, Nork SE, et al. Quantification of the upper and second sacral segment safe zones in normal and dysmorphic sacra. *J Orthop Trauma*. 2010; 24:622–9. [PubMed: 20871250]
2. Conflitti JM, Graves ML, Routt ML Jr. Radiographic quantification and analysis of dysmorphic upper sacral osseous anatomy and associated iliosacral screw insertions. *J Orthop Trauma*. 2010; 24(10):630–6. [PubMed: 20871251]
3. Moed BR, Geer BL. S2 iliosacral screw fixation for disruptions of the posterior pelvic ring: a report of 49 cases. *J Orthop Trauma*. 2006; 20(6):378–83. [PubMed: 16825961]
4. Moed BR, Whiting DR. Locked transsacral screw fixation of bilateral injuries of the posterior pelvic ring: initial clinical series. *J Orthop Trauma*. 2010; 24(10):616–21. [PubMed: 20871249]
5. Gardner MJ, Routt ML Jr. Transiliac-transsacral screws for posterior pelvic stabilization. *J Orthop Trauma*. 2011; 25(6):378–84. [PubMed: 21577075]
6. Routt ML Jr, Simonian PT, Agnew SG, et al. Radiographic recognition of the sacral alar slope for optimal placement of iliosacral screws: a cadaveric and clinical study. *J Orthop Trauma*. 1996; 10(3):171–7. [PubMed: 8667109]
7. Ricci WM, Mamczak C, Tynan M, et al. Pelvic inlet and outlet radiographs redefined. *J Bone Joint Surg Am*. 2010; 92(10):1947–53. [PubMed: 20720137]
8. Routt, ML. Posterior Pelvic-Ring Disruptions: Iliosacral Screws, in *Master Techniques in Orthopaedic Surgery- Fractures*. Wiss, DA., editor. Lippincott Williams & Wilkins; Philadelphia, PA.: 2006. p. 649-667.
9. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977; 33(1):159–74. [PubMed: 843571]
10. Ebraheim NA, Xu R, Biyani A, et al. Morphologic considerations of the first sacral pedicle for iliosacral screw placement. *Spine (Phila Pa 1976)*. 1997; 22(8):841–6. [PubMed: 9127914]
11. Noojin FK, Malkani AL, Haikal L, et al. Cross-sectional geometry of the sacral ala for safe insertion of iliosacral lag screws: a computed tomography model. *J Orthop Trauma*. 2000; 14(1):31–5. [PubMed: 10630800]
12. Carlson DA, Scheid DK, Maar DC, et al. Safe placement of S1 and S2 iliosacral screws: the “vestibule” concept. *J Orthop Trauma*. 2000; 14(4):264–9. [PubMed: 10898199]
13. Day AC, Stott PM, Boden RA. The accuracy of computer-assisted percutaneous iliosacral screw placement. *Clin Orthop Relat Res*. 2007; 463:179–86. [PubMed: 17960680]

Figure 1.

A midline sagittal CT reconstruction image is shown, demonstrating the measurement of the angle between the anterior S1 body and the perpendicular to the CT gantry (routine axial CT plane).

Figure 2.

A midline sagittal CT reconstruction image is shown, demonstrating various planes of reference for the S1 sacral body. In this example, the angle between the anterior S1 body tangent and the routine axial CT plane is 12 degrees, the posterior S1 body tangent angle is 24 degrees, and the bisector angle is 18 degrees.

Figure 3.

A paramedian sagittal CT reconstruction image through the right S1 neuroforamen (inset) is shown, demonstrating the measurement of the angle between the sagittal orientation of the right S1 neuroforamen and the routine axial CT plane.

Figure 4.

A CT Outlet image created by orienting the CT reconstruction in the plane of the bisector of the midline anterior and posterior S1 body tangents (inset).

Figure 5.

A CT Inlet image created by orienting the CT reconstruction in the plane perpendicular to the bisector of the midline anterior and posterior S1 body tangents (inset).

Figure 6.

A parallel to a line drawn connecting the posterior iliac crests seen on each CT image defined the orientation of ideal trans-sacral screws (a). Ideal sacro-iliac screw trajectories were defined by measuring the smallest distance between the limiting osseous borders and drawing a perpendicular line through this midpoint (b), maximizing the surrounding bone in the ala throughout its course.

Figure 7.

Measurement of the distance between limiting osseous borders (from below or posterior to the L5 nerve root and intrapelvic structures to above or anterior to the S1 nerve roots and neural canal) for a transverse screw in the upper sacral segment using a routine CT image (a), a CT Outlet image (b), and a CT Inlet image (c).

Figure 8.

Measurement of the smallest perpendicular distance between limiting osseous borders (from below or posterior to the L5 nerve root to above or anterior to the S1 nerve root) for a screw parallel to the axis of the sacral ala in the right upper sacral segment using a routine CT

image (a), a CT Outlet image (b), and a CT Inlet image (c). Angles of screw trajectory are measured between the transverse posterior iliac reference line and the axis of the ala.

Figure 9.

A histogram of the distribution of the angles between the sacral axes and the routine CT plane. Skewness of the curve is 0.164 and excess kurtosis is -0.223 (SE kurtosis 0.574, $p > 0.05$), suggesting a symmetric distribution that does not significantly differ from a standard normal distribution.

Figure 10.

A 66 year old male, after being run over by a tractor, sustained bilateral superior and inferior pubic rami and a left zone 2 sacral fractures (a) and developed a sacral nonunion (b).

Midline sagittal CT reconstructions are created from an axial cut (c). Note that the axial CT cut does not provide useful information for planning trajectory of ilio-sacral screws. A CT Outlet (d) is created in a plane parallel to the sacrum (d - inset) and CT Inlet views (e and f) are created in a plane perpendicular to the sacrum through the desired sacral level (S1 e – inset, S2 f – inset). The CT Inlet and CT Outlet views demonstrate that a trans-sacral screw trajectory is possible through S2 but difficult through S1. Note the correlation of CT views

with intra-operative fluoroscopy (round insets). An immediate post-operative radiograph (g) and 8 month postoperative CT scans (h and i) demonstrate screw positions that correlate with the pre-operative plan and show fracture union.

Table 1

	n	Anterior S1 angle [deg (St Dev)]	p	Anterior S1 - Neuroforamen [deg (St Dev)]	p
Male	44	21.48 (9.40)		12.80 (7.68)	
Female	24	20.67 (7.95)	0.72	13.81 (7.44)	0.6
Dysmorphic	25	22.76 (9.20)		13.88 (7.90)	
Normal	43	20.28 (8.63)	0.27	12.73 (7.41)	0.55

S1 anterior body tangent angles and differences between S1 anterior body tangent and neuroforamen profile angles.

Table 2

	<u>Routine CT, right</u>	<u>Routine CT, left</u>	<u>CT Inlet, right</u>	<u>CT Inlet, left</u>	<u>CT Outlet, right</u>	<u>CT Outlet, left</u>
<i>All</i>						
<u>Sacro-iliac style screw angle (deg)</u>	25.40	24.56	14.42	11.97	24.45	23.56
<u>St Dev</u>	6.23	7.20	6.47	5.84	5.83	6.25
<u>Max</u>	40.75	43.17	35.55	35.06	37.07	41.99
<u>Min</u>	13.00	9.96	3.06	2.34	10.37	14.33
<i>Normal</i>						
<u>Sacro-iliac style screw angle (deg)</u>	24.04	23.09	13.54	11.45	23.04	21.98
<u>St Dev</u>	5.18	6.43	4.87	4.61	4.60	5.68
<u>Min</u>	14.30	9.96	6.54	2.34	14.71	14.33
<u>Max</u>	37.43	37.84	28.70	23.82	33.36	41.99
<i>Dysmorphic</i>						
<u>Sacro-iliac style screw angle (deg)</u>	27.75	27.10	15.94	12.86	26.87	26.27
<u>St Dev</u>	7.22	7.86	8.45	7.53	6.95	6.36
<u>Min</u>	13.00	12.01	3.06	3.04	10.37	14.33
<u>Max</u>	40.75	43.17	35.55	35.06	37.07	40.73
<u>Normal - Dysmorphic (deg)</u>	-3.72	-4.01	-2.41	-1.41	-3.83	-4.29
<u>p</u>	<0.05	<0.05	0.65	0.34	<0.01	<0.01

Angles of insertion for oblique sacro-iliac type screws for each set of images, and differences between normal and dysmorphic sacra.

Table 3

	S1 Sacral style [mm (St Dev)]	S1 R Sacroiliac style [mm (St Dev)]	S1 L Sacroiliac style [mm (St Dev)]	S2 Sacral style [mm (St Dev)]
<u>Routine axial</u>	8.95 (5.73)	17.22 (3.16)	17.62 (2.83)	9.36 (2.41)
<u>CT Inlet</u>	14.40 (6.33)	17.59 (3.58)	17.84 (3.62)	11.39 (2.29)
<u>CT Outlet</u>	8.95 (5.53)	16.19 (3.01)	16.66 (2.88)	9.94 (2.41)
	Difference [mm (<i>p</i>)]			
<u>Routine – CT Inlet</u>	–5.46 (<0.01)	–0.38 (0.22)	–0.22 (0.51)	–2.03 (<0.01)
<u>Routine – CT Outlet</u>	–0.01 (0.94)	1.03 (<0.01)	0.96 (<0.01)	–0.58 (<0.01)

Measured safe zone values and differences between standardized images and routine images.

Table 4

Intraclass Correlation

		Absolute	Consistency
	S1 bisector angle	<i>0.82</i>	<i>0.81</i>
	S2 bisector angle	0.75	0.74
Routine Axial CT			
	Sacral style S1	<i>0.93</i>	<i>0.93</i>
	Right SI style S1	0.60	0.64
	Left SI style S1	0.76	<i>0.85</i>
	Sacral Style S2	0.56	0.53
CT Inlet			
	Sacral style S1	<i>0.92</i>	<i>0.91</i>
	Right SI style S1	0.57	0.57
	Left SI style S1	0.57	0.56
	Sacral Style S2	0.52	0.74
CT Outlet			
	Sacral style S1	<i>0.91</i>	<i>0.91</i>
	Right SI style S1	<i>0.80</i>	<i>0.89</i>
	Left SI style S1	<i>0.92</i>	<i>0.94</i>
	Sacral Style S2	0.49	0.46

Inter-observer reliability testing results using Intraclass Correlation (ICC). Values between 0.81-1.0 represent very high agreement, and are in bold italics. Other values are between 0.41-0.60 (moderate agreement) and 0.61-0.80 (substantial agreement).