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Can Partially Threaded Cannulated Screws Be Better Designed to Maximize Purchase in the Sacrum?

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ABSTRACT: Sacroiliac screw fixation involves the use of cannulated, partially or fully threaded screws. Current partially threaded screws have standardized thread lengths involving a small portion of the screw regardless of its overall length. Forty uninjured computed tomography images were evaluated for distances from the lateral iliac cortex to the lateral sacral cortex at the first and second sacral segments. No difference in measurements were observed for gender, age, or body mass index. Using a smooth segment value of 32 mm, a significant increase in thread lengths is achievable allowing for a novel sacroiliac screw design to achieve greater purchase in the sacrum.

KEY WORDS: pelvic fracture, iliosacral screw, sacroiliac screw, cannulated screw, computed tomography

I. INTRODUCTION

Closed reduction and percutaneous fixation is the treatment of choice for most unstable posterior pelvic and sacral injuries.[1] Percutaneous sacroiliac (SI) screw placement allows for definitive fixation of posterior ring injuries with minimal blood loss, less operative time, and fewer wound complications than open reduction and internal fixation.[1] Surgical techniques for SI screw placement have evolved with time.[2] Improved understanding of pelvic and sacral anatomy has allowed for routine placement of SI screws with high levels of safety and success.[3]

Current methods for SI screw fixation involve the use of cannulated, partially or fully threaded screws. While fully threaded screws exhibit greater resistance to shear and strain at the injury site, they lack intrinsic lag function and therefore the near-cortex must be over-drilled to achieve compression.[4] This risks intrusion of the screw head into the ilium, particularly in patients with poor bone quality particularly in the absence of a washer. Currently available partially threaded screws have standardized thread lengths that involve a small portion of the screw regardless of its overall length.[5] Consequently, a significant portion of the screw is smooth and provides no purchase in the sacrum.

The objective of this study was to perform an imaging-based anatomic evaluation of the posterior pelvic ring to determine if the distance between the lateral cortex of the ilium and medial aspect of the SI joint (lateral sacral cortex) is a consistent value that may afford an anatomic basis upon which novel sacroiliac screws may be developed. We hypothesized that this distance would be consistent within the study population and follow a normal (Gaussian) distribution.

II. METHODS

Following institutional review board (IRB) approval, 40 adult patients with computed tomographic (CT) imaging of the uninjured pelvis were identified by query of our institution's trauma database for CPT codes 27506 and 27507 (open treatment of femoral shaft fracture) between April 2013 and September 2015. Patients with sacral dysmorphism, pelvic neoplasm, suboptimal imaging (e.g., malrotation, incomplete series), or history of trauma or surgery involving the pelvis or sacrum were excluded.

Diagnosis of sacral dysmorphism was made on the basis of criteria previously described by Miller et al. and by review of CT imaging alone.[6] Patient charts were also reviewed for demographic data including age, gender, height, and body mass index (BMI).

All scans were completed by a high-definition CT scanner with 2 to 3-millimeter sections. Measurements were made by two investigators (SB, II) utilizing digital calipers on a high-resolution picture archiving and communication system (Centricity, GE Healthcare, Chicago, IL, USA). All imaging was reviewed by both investigators to mitigate inter-observer discrepancy. The primary dimension of interest was the bony depth to the lateral sacral cortex (dLSC) at the first and second sacral segments (Fig. 1). This was the distance between the lateral iliac cortex and lateral sacral cortex (medial aspect of the SI joint) and would correspond to the length of the non-threaded portion of the proposed screw design (Fig. 2). This distance was calculated for hypothetical sacroiliac screws placed at S1 and S2 for each uninjured pelvis.

First, an axial image corresponding to the sacral "vestibule," as previously defined in the literature, was identified for the upper sacral segment.[7] Linked coronal and sagittal plane reformats were utilized to locate the appropriate screw trajectory. The distance between the lateral cortex of the ilium and the lateral sacral cortex along the proposed trajectory of the screw was measured based on the coronal image (Fig. 1). The distances from the lateral ilium to the midline of the S1 sacral body (depth to midline, dML; Fig. 3) and zone 2 of the sacrum (adjacent to the neuroforamina) were also recorded (depth to zone 2, dZ2). Finally, screw length was estimated by measuring the distance from the lateral ilium to a point midway between the midline of the sacral body and contralateral neuroforamen. This value was rounded to the nearest multiple of 5 for consistency with screw lengths available in current cannulated screw systems. Measurements for the second sacral segment were completed in similar fashion.

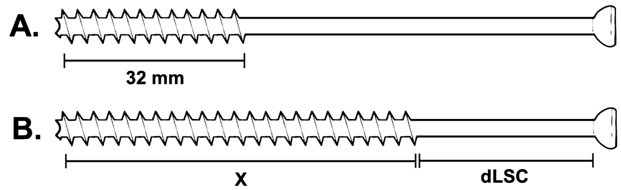

FIG. 2: Comparison of conventional 32-mm partially threaded screw (A) to proposed screw design (B). In the proposed screw design, the smooth shaft segment is a constant value corresponding to the "dLSC," while the threadform segment "x" is longer and varies with the overall screw length.

A. Statistical Analysis

All statistical analyses were performed in SPSS version 23 (IBM Corporation, Armonk, NY). Descriptive statistics were obtained for each measurement of interest. Histograms were constructed individually for each measure and the Shapiro–Wilk test for normality was used to confirm an approximately normal (Gaussian) distribution. Additionally, the kurtosis was estimated for each measure. Reference

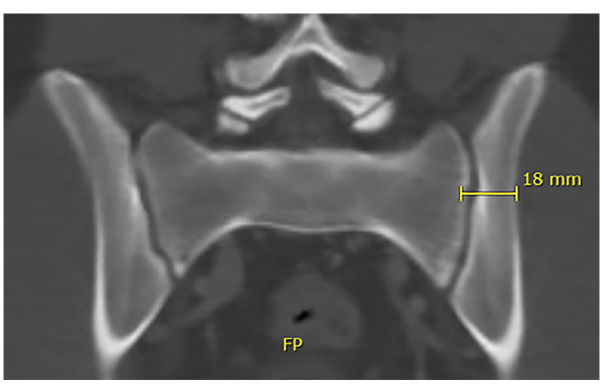

FIG. 1: Exampled: Depth to lateral sacrum (dLSC)

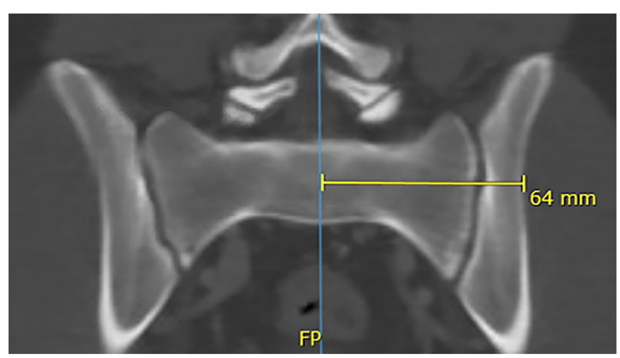

FIG. 3: Example: Depth to midline (dML)

ranges for each measurement were statistically determined to capture 99.7% of observations by utilizing a three standard deviation range. Differences in the means for each parameter were compared between male and female patients utilizing independent *t*-tests. Finally, Pearson correlation was used to determine associations between radiographic variables and patient age, height, and BMI.

III. RESULTS

Overall, 200 patients were screened of whom 93 had available CT imaging of the pelvis. Fifty-three patients were excluded from analysis including 26 patients with pelvic/sacral trauma and 20 patients with sacral dysmorphism (Fig. 4). The final study population included 23 male patients (57.5%) and 17 females (42.5%). The average patient age at the time of presentation was 51.8 years (range 19 to 82 years). The average patient height was 67.4 inches (range 60 to 73 inches) and the average BMI was 26.8 kg/m^2 (range 15.2 to 44.4 kg/m^2).

The mean depth to the lateral sacral cortex at S1 was 24.8 mm (dLSC-S1; range 20 to 30 mm, SD ± 2.3). The interquartile range was 3.0 mm, consistent with low variability. Mean dLSC-S1 did not differ significantly between male and female patients. Similarly, dLSC-S1 was not significantly correlated with patient age, height, or BMI (Table 1). Results of the Shapiro–Wilk test indicated that the observed values for dLSC-S1 followed a normal distribution about the mean (Fig. 5; 0.96, p = 0.264). Similarly, the kurtosis was estimated at –0.18 (p = 0.810) consistent with a normally distributed sample. Accordingly, the 3 SD range for dLSC-S1 was determined to be 17.9 to 31.7.

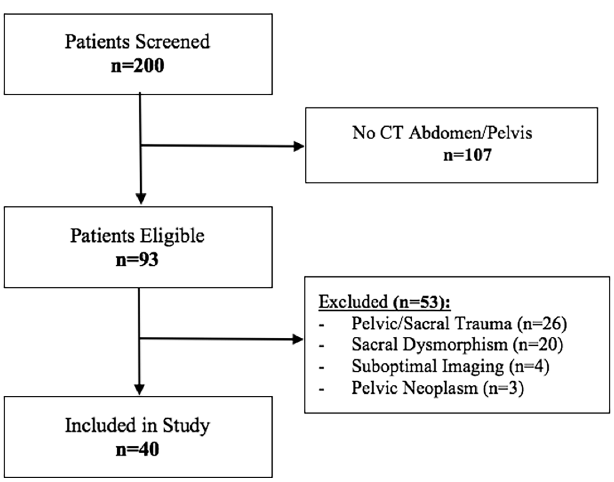

FIG. 4: Flow diagram demonstrating patient selection process

Mean depth to the lateral sacral cortex at S2 was 22.9 mm (dLSC-S2, range 18 to 19 mm; SD ± 2.7). The interquartile range was 4.75 mm. As with measurements at S1, no difference was observed on the basis of gender, age, or BMI (Table 1). Larger values for dLSC-S2, however, were significantly correlated with increasing patient height (0.386, p = 0.014). A normal distribution for values at S2 was also confirmed by Shapiro–Wilk analysis and the 3 SD range for dLSC-S2 was determined to be 14.8 to 31.0. (Fig. 6; 0.96, p = 0.209). The kurtosis for dLSC-S2 was estimated at –0.413 (p = 0.575). The mean distance from the lateral iliac cortex to the midline of the S1 body was 77.2 mm (dML-S1; range 64 to 88 mm; SD ± 6.3), while the distance to the midline of S2 was 66.7 (dML-S2; range 57 to 78 mm; SD ± 5.13). Finally, the mean distance from the lateral iliac cortex to zone 2 at S1 was 61.6 (dZ2-S1; range 48 to 73; SD ± 5.6) and 52.2 at S2 (dZ2-S2; range 42 to 62; SD ± 4.4).

Employing a standardized length for the smooth shaft segment of each screw will increase the length of the thread-forms proportionate to the total length of each screw (Fig. 2). Using a smooth segment of 32 mm based on the 3 SD ranges for dLSC-S1 and dLSC-S2 described above, thread lengths ranged from 38 to 68 mm for screws templated from the study population (70 to 100 mm total screw length). This represented and average increase in thread lengths of 165.6% (range 118.8–212.5%) at S1 and 130.5% (100.0–165.6%) at S2 when comparison is made to partially threaded screws in current-use, the most common of which possess a maximum thread length of 32 mm.[8]

IV. DISCUSSION

Closed reduction and percutaneous fixation has become the preferred treatment for most unstable posterior ring injuries, permitting injury

TABLE 1: Pearson correlation for clinical and radiographic variables

Variable	Age	Height	Body mass index (BMI)	dLSC-S1
Height	**–0.395 (0.012)**			
BMI	0.101 (0.562)	0.024 (0.890)		
dLSC-S1	0.050 (0.759)	0.302 (0.058)	–0.156 (0.371)	
dLSC-S2	0.062 (0.704)	**0.386 (0.014)**	–0.006 (0.971)	0.189 (0.242)

P-values are highlighted between parentheses, and statistically significant values are shown in bold.

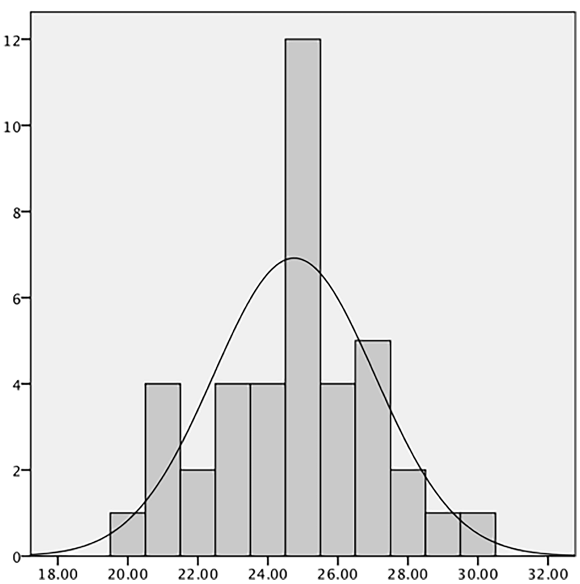

FIG. 5: Histogram for dLSC at S1 demonstrating normal distribution

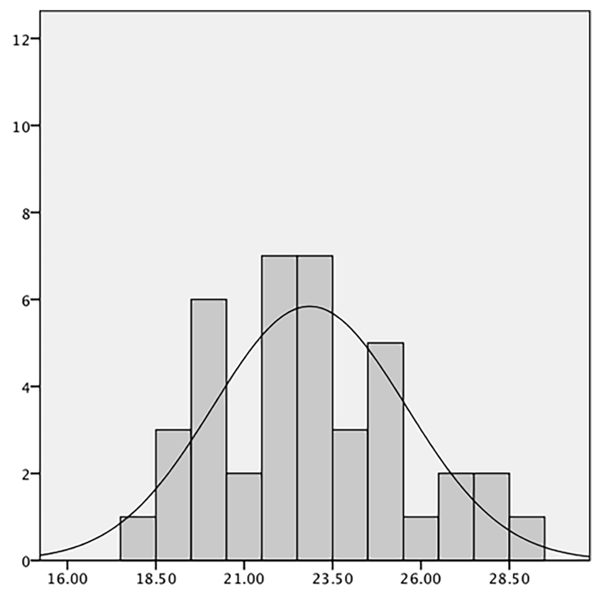

FIG. 6: Histogram for dLSC at S2 demonstrating normal distribution

stabilization with less operative time, fewer complications, and comparable stability to open techniques.[1] An improved understanding of pelvic and sacral anatomy, including radiographic and templating techniques, has allowed SI screws to be placed with high levels of safety and success.[3] Despite recent progress in surgical techniques, conventional partially threaded screws with limited thread lengths remain the primary means of fixation. A simple modification to screw design, however, may enhance purchase in the sacrum by extending the threaded segment of the screw and maintaining a shorter, smooth shaft to retain lag function across the SI joint.

We performed an imaging-based analysis of the posterior pelvic ring to determine if the distance between the lateral iliac and sacral cortices is constant. In support of our hypothesis, we observed consistent and normally distributed values for the bony depth to the lateral sacral cortex at both S1 and S2 with low variability. Importantly, no difference was observed between male and female patients despite sexual dimorphisms in male and female pelvic structure.[9] Similarly, no correlation was observed between lateral sacral depth and patient age or BMI. Patient height did correlate significantly with sacral depth at S2 with larger values occurring more commonly in taller patients. Sacral depth at S1 approached statistical significance with patient height. This relationship is predictable as taller patients would be expected to have larger bony structures than their shorter counterparts. Despite this, the variability in values observed is quite low.

Given normal distributions, 3 SD ranges corresponding to nearly all (99.7%) expected values for the population would be 17.7 mm to 31.5 mm for bony depth at S1 and 14.8 mm to 31.0 mm at S2. Of primary interest is the upper limit of each range as these values define the minimum length for the smooth segment of the proposed screw design, allowing it to retain lag function across the SI joint. While there is some variation in current screw designs, a common range of thread-form length is 16 mm to 32 mm.[5] Our results suggest an increase in thread-form length of up to 200% or greater for screws templated from the study population. Fully threaded screws have been shown to have greater initial stiffness, pullout strength, and failure strength when compared to partially threaded screws in a simulated fracture model.[4] Similarly, lower thread pitch (i.e., finer threads) and increased thread lengths have also been shown to improve pullout strength in biomechanical studies.[10] Furthermore, a cadaveric study by Kramer et al. demonstrated improved pullout strength for long (32 mm) partially threaded cancellous screws versus short (16 mm) partially threaded screws placed into the S1 body.[11] Therefore, increasing the thread-form length of partially threaded sacroiliac screws could be expected to improve pullout strength and failure strength of posterior ring constructs.

The implications of increased screw purchase within bone are particularly relevant for geriatric patients. While most geriatric pelvic fractures are managed non-operatively, unstable posterior ring and sacroiliac dislocations may benefit from stabilization.[12] Poor screw purchase in osteoporotic bone presents a unique challenge during treatment of these injuries. Cement augmentation of SI screws has had mixed results and other fixation methods may not be suitable in elderly patients.[8] Sacroiliac screws with longer thread forms, however, may decrease risks for implant loosening and failure in this patient population through improved resistance to pullout. Ramaswamy et al. observed a direct correlation between screw holding power and the quantity of threads engaging in foam block models of varying density.[13] Among four small fragment cannulated screws evaluated by Ramaswamy and colleagues, the screw design possessing the longest thread form exhibited the best holding power in low density models.[13] Optimizing pullout strength properties of sacroiliac screws may permit safer application in geriatric patients and improve treatment strategies for geriatric pelvic fractures.

Corridor diameter was not evaluated in this study as it has been examined in earlier studies with more robust methodologies for approximating its size in three dimensions.[7] Increased precision in screw placement, however, may be required due to the higher likelihood that the screw threads will lie adjacent to the neuroforamen.[14] Preoperative planning and determination of corridor diameter using previously described means will be crucial to avoid breaching the neuroforamina.

This study had several limitations. First, coronal, sagittal, and axial imaging was based on the formatting protocols from the initial scan. Reformatting the images to obtain true inlet and outlet views was not performed. The coronal image was referenced with the axial and sagittal series to identify the lateral start point and projected screw path. Most surgeons do not have access to advanced software allowing them the ability to manipulate the CT images to a true inlet and outlet view and they will template off the injury CT scan. Second, interobserver and intraobserver reliability was not measured. Given the low variability in measurements observed, assessing inter-rater reliability would have been of low utility. Patients were excluded based on criteria defined by Miller et al. for sacral dysmorphism.[6] While these criteria exclude cases of obvious dysmorphism, a broad range exists between normal and dysmorphic sacra. Additionally, our results may not be generalizable to patients with sacral dysmorphism and further study may be required to define these anatomic parameters for patients with dysmorphic sacra. Finally, a relatively small number of patients were evaluated in this study. The size of the study population, however, is similar to prior CT-based anatomic studies of the pelvis.[14]

V. CONCLUSION

To our knowledge, this is the first study to define the distance from the lateral ilium to the lateral sacrum and examine its application in optimizing treatment of posterior pelvic trauma. We showed the distance from the lateral ilium to lateral sacrum is consistent and this information can be used to create improved partially threaded screws to optimize purchase within the sacrum during the surgical fixation of posterior pelvic ring injuries.

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