Author's response to reviews

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Digital Anatomical Measurements of Safe Screw Placement at Superior Border of the Arcuate Line for Acetabular Fractures

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Abstract

Purpose: To obtain the safe and effective screw angles and depths at acetabular area of the fixation route along the superior border of the arcuate line to the pubic tubercle, so as to avoid screw penetration of the hip joint. Method: A total of 98 complete pelvic computed tomography (CT) scans of adults eliminated pelvic diseases were collected. Each person’s CT scans were reconstructed to create a three-dimensional pelvic model. A curve of the fixation route was delineated and. Five cross-sections from the pubic tubercle to the sacroiliac joint direction were constructed perpendicularly to the curve. The minimum safe angle $\alpha$ and the maximum safe and effective angle $\beta$ were measured in the middle three sections. The safe screw depths, $d_1$ and $d_2$, were obtained in all the five sections. Results: The ranges of safe and effective screw insertion angles for the second, third, fourth cross-section were $21.09 \pm 13.57^\circ$~$40.45 \pm 13.60^\circ$, $30.43 \pm 14.05^\circ$~$47.54 \pm 12.67^\circ$, $23.84 \pm 11.60^\circ$~$37.13 \pm 8.45^\circ$, respectively. The maximum screw depths for the five sections were $15.89 \pm 3.80$ mm, $58.83 \pm 27.66$ mm, $42.94 \pm 22.41$ mm, $72.43 \pm 6.73$ mm, $40.99 \pm 6.33$ mm. The comparisons between male and female showed significant differences for $d_1$ of section 2, 3, 4, $\alpha$ of section 2, 3, 4, $d_2$ of section 4 ($p<0.05$). Conclusions: The minimum safe angles for female should be pointing to quadrilateral surface greater than the ones of male, yet the maximum safe and effective angles maintain at the same level for both. Keywords: acetabular fracture; screw placement; arcuate line; complication; digital measurement.
Introduction

The diagnosis, classification, reduction and fixation of acetabular fracture have been regarded difficult for its deep anatomical location and complicated surroundings. The injuries of articular surface increase the incidence of complications, such as malunion and traumatic osteoarthritis, to 50% - 60%, which greatly affect the life quality of patients\textsuperscript{1-3}. As anatomical reduction plays an important role in the clinical outcome and the incidence of complications, the internal fixation with screw-plate system or screws only is getting more and more accepted by orthopedic surgeons\textsuperscript{4}. During the procedure of acetabular fixation choosing ilioinguinal or Stoppa approach, screws might be placed at a wrong direction and penetrate into the hip joint for the articular surface could not be observed directly. This can result to severe complications of aggravated osteoarthritis and chondrolysis in further\textsuperscript{5}. Several methods, including intraoperative radiographs or fluoroscopy, auscultation of the hip with movement, and direct observation of the hip joint, have been reported to prevent this complication, which increase the operation tome and trauma\textsuperscript{4, 6, 7}. Only by deep understanding of the unique three dimensional structure of acetabular area, can orthopedic surgeons place screws safely and accurately to avoid the screw penetration of the hip joint\textsuperscript{8, 9}.

According to the previous anatomical researches of the safe paths for screw placement on the anterior or posterior column, the projections of acetabulum on anterior and posterior column are termed anterior region and posterior region, respectively. For anterior column region, an absolute risky region was delimited in which screw penetration of the hip joint will happen. And the rest part was relatively risky region in which screw penetration could be avoided with the screw parallel to the quadrilateral surface, while the screw might also penetrate into the hip joint if it tilts toward lateral\textsuperscript{8}. For posterior column region, the screw could not be inserted at the absolute risky region as it is safe to be placed at a proper angle at the relatively risky region\textsuperscript{10}. It is worth noting that the existing researches obtained the safe paths and safe angles by measurements on cadaveric bone, which contains a certain level of artificial error during the projected area of acetabulum, the determination of the cross-section, the construction of the supplementary lines, etc. Besides, the sample sizes of these researches are relatively low, ranging from 30 to 46, which are relatively small to evaluate the general situation of population. Digital three-dimensional (3D) measurements, based on CT reconstruction, have the same accuracy and reliability as traditional measurements, and this 3D technology has been considered a more efficient method for orthopaedic anatomic studies, design, and optimization of implants\textsuperscript{11-13}.

A retrospective observational study by digital reconstruction and 3D measurements of a large sample of normal adult pelvic CT scans was conducted by the authors. The aim of this study was to obtain the safe and effective screw angles and depths at
acetabular area of the fixation route along the superior border of the arcuate line to the pubic tubercle in a more objective method. The application of engineering design software in this study guaranteed the objectivity and accuracy of the measured parameters.

**Patients and methods**

**Samples and equipment**

We collected the computed tomography scans from out-patients with varicose vein of lower limb, who needed enhanced computed tomography scan (CT scan) from pelvis to feet. Each patient was eliminated pelvic deformity, trauma, tumor and other diseases by computed tomography results and inquesting history. From December 2009 to November 2010, 98 complete pelvic computed tomography scans of unrelated ethnic Han Chinese adults (mean age 60.1 (22-91) years, 60 men, 38 women) were collected from the medical image database of the department of radiology of Shanghai People’s Hospital, a large comprehensive hospital. During CT scanning, patients kept the standard anatomical horizontal position with lower limbs unbent. All the CT scans were performed at 120 kV and 300 mA with a slice thickness of 0.75 mm by a 64-channel CT, Light Speed VCT XTe (GE Healthcare; Milwaukee, WI, USA), and the scanning time of each slice was 200 ms. There were approximately 380 DICOM format CT images for the pelvic part of each patient. For the data was collected from out-patients retrospectively, the height and weight of the patient were not recorded in this study. The study was performed with the help of the following software: the interactive medical image control system MIMICS 13.0, the reverse engineering software Geomagics 10, the engineering design software Imageware 23.0, and the mechanical design software Unigraphics NX 7.0. The study was approved by the Review Board of Shanghai First People’s Hospital.

**Measurement of parameters**

Each patient’s DICOM format CT images were imported to Mimics 13.0. After removing the soft tissue by thresholding segmentation, region growing, and a subsequent smoothing process, an entire 3D digital pelvic model was established and saved in Stereo Lithography (STL) format. The pelvic model was imported to the Geomagics software as a mesh model in the STL format. The horizontal, coronal and sagittal plane were determined in the first place. According to the standard in the anatomical position, the pubic tubercle and anterior superior iliac spine are in the same coronal plane. The plane passing the midpoint of the pubic symphysis, the midpoint of the anterior border of the sacral promontory and the coccyx tip was identified the sagittal plane. And the plane constructed perpendicularly to the sagittal and the coronal plane was the horizontal plane. Along with the route from the pubic tubercle, pubis pecten, iliopubic eminence,
arcuate line, and sacroiliac joint, more than 15 points were picked at the cortical
surface 5.0mm lateral to the pelvic brim in the superior border of the arcuate line to
draw the space curve of the bone surface. All the objects were saved in STL format
and imported to the Imageware software to fit an optimal ball by cloud point and
filling it into the acetabular fossa. And all the subjects were saved in IMW format and
imported to the Unigraphic NX.
A cross-section through the ball center was made perpendicularly to the aforesaid
curve. The two planes translated forwardly and backwardly along the curve from the
cross-section by the radius of ball intersect the curve at two points. Divide the space
curve with the aforementioned two points as endpoints into four equal parts. After
constructing five normal planes through the two endpoints and three decile points to
the space curve, five acetabular area sections were obtained by intersecting five
normal planes and the pelvis, respectively (Fig. 1). The five sections were recorded as
section 1, 2, 3, 4, and 5 from the pubic tubercle to the sacroiliac joint direction (Fig. 2).
The intersection point of each cross-section and the space curve was the screw
entrance point at this section.
To each cross-section, a normal plane was constructed perpendicularly to the bone
surface through the screw entrance point and intersected the section at an intersection
point. To section 1 and 5, the distance between the screw entrance point and the
intersection point was measured and recorded as the depth of the screw, d (Fig. 3).
Due to the same shape, section 2 and 3 were measured with the same methods. An arc
was fitted from the shape of acetabulum by picking several points along the edge of
acetabulum, radius of which was expanded by 5.0 mm to represent the outline of the
acetabulum considering the thickness of subchondral bone. The line tangent to the
expanded arc through the screw entrance point was recorded as the depth of the screw,
d₁. The angle between the tangent line and the normal plane was recorded as α.
Construct an arc with the radius of 14.0mm and intersect it with the quadrilateral
surface at a point. And the angle between the line connecting the screw entrance point
and the intersection point and the normal plane was recorded as β (Fig. 4). To section
4, the depth of screw d₁ and the angle were measured with the method same as
section 2 and 3. An arc was fitted by picking several points at the concave of the
quadrilateral surface. The line tangent to the arc through the screw entrance was
recorded as the depth of screw, d₂. The angle between the tangent line and the normal
plane was recorded as β (Fig. 5).
Statistical analysis
The data were expressed as mean±standard deviation and analyzed by using the
descriptive methods with SPSS 19.0. The data distributions were analyzed with
normality tests. A p value less than 0.05 was considered to be statistically significant.
All the 98 pelvis were categorized by gender. We compared the mean values of the
relative parameters between different groups with T test.

**Results**

The safe screw depths of all the five cross-sections are 15.89±3.80 mm, 58.83±27.66 mm, 42.94±22.41 mm, 72.43±6.73 mm and 40.99±6.33 mm (Table 1). The ranges of safe and effective screw insertion angles for section 2, 3, 4 are 21.09±13.57° ~ 40.45±13.60°, 30.43±14.05° ~ 47.54±12.67°, 23.84±11.60° ~ 37.13±8.45°. The comparisons between male and female showed significant differences for $d_1$ of section 2, 3, 4, $\alpha$ of section 2, 3, 4, $d_2$ of section 4 (p<0.05). All the comparisons of angle $\alpha$ between different screw depths showed statistical significance, while all the comparisons of angle $\beta$ showed no statistical significance (Table 3).

**Discussion**

The results of this anatomical measurement provided the references for screw placement of acetabular fractures, including the minimum effective angle, maximum safe angle and screw depth. In addition, the safe and effective angles were presented with respect to the bone surface, which would facilitate screw placement for clinical applications. Some related studies focusing on screw placement of anterior and posterior risky region of acetabulum were reported in previous literature. Benedetti sectioned cadaveric specimens at 1.0-cm intervals, beginning at the level of the inferior border of the acetabulum (junction between the anteroinferior edge of the acetabulum and the most anterolateral edge of the superior ramus of the pubic bone). The plane of the cross-section was perpendicular to the anterior column. For 0.5-cm entrance points lateral to the pelvic brim at 1.0 cm, 2.0 cm, 3.0 cm superior to the inferior margin of the acetabulum, the safe medial angulations were 24.9 ± 4.4°, 29.2 ± 5.5°, 20.7 ± 4.3°, with respect to the perpendicular of the longitudinal axis of the anterior column without violation of the hip joint. The results of this study were correspondent with Benedetti’s study, although there is a difference of reference plane. However, the relative position between the longitudinal axis and the screw entrance point at fracture fragments might be changed when suffering from acetabular fractures. Consequently, the angulations this study provided might not be reliable for screw placement during clinical surgeries. For posterior column region, Ebraheim constructed cross-sections perpendicularly to the posterior column at 1.0-cm intervals. The safe anatomical pathways for screws placed at entrance points of 2.0 cm and 3.0 cm medial to the lateral acetabular margin and angled medially 45° and 15°, respectively. This study did not provide the essential parameters of safe pathway from an anterior approach, which is also commonly used for complex acetabular fractures involving posterior column. The comparisons between male and female were conducted to find the gender
differences of the range of safe and effective angle, the safe screw depths. All the
table angles $\alpha$ in section 2, 3, 4 showed significantly larger than the male angles. It
can thus be seen that to avoid the screw penetration of the hip joint, the minimum safe
angles for female should be pointing to quadrilateral surface greater than the ones of
male. All the angles $\beta$ in section 2, 3, 4 between male and female showed no
significant difference, indicating that the maximum safe and effective angles maintain
at the same level for both male and female.

As the existing researches, based on arcuate line of acetabulum, obtained the safe
paths and safe angles by measurements on cadaveric bone, some procedures during
the measurements, including the projected area of acetabulum, the determination of
the cross-section, the construction of the supplementary lines, etc, contain a certain
level of artificial error. These procedures were completed artificially without objective
methods. The cross-sections sectioned at 1.0-cm intervals for all sizes of pelvis might
locate at different anatomical positions, which made the measurement results and
comparisons of these cross-sections less reliable and valuable. Besides, the sample
sizes of these researches are relatively low, ranging from 30 to 46, which are
relatively small to evaluate the general situation of population. Our study applied
digital approaches to divide the cross-sections and measure the angles, with a
relatively larger sample size, which would provide more reliable reference for
acetabular surgeries.

Limitations and shortcomings
In this study, all subjects were unrelated ethnic Han Chinese recruited from Shanghai
First People’s Hospital. It would be interesting to conduct independent studies in other
ethnic populations for comparison. In addition, due to the different medical conditions
of each sample, we could not gather the complete data of each sample’s height and
weight. It would be meaningful to perform a follow-up study, which expands the
analysis including these parameters.

Conclusion
By digital reconstruction and 3-dimensional measurement of a large sample of normal
adult pelvic CT scans, this study obtained the safe and effective screw angles and
depths at acetabular area of the fixation route along the superior border of the arcuate
line to the pubic tubercle. The minimum safe angles for female should be pointing to
quadrilateral surface greater than the ones of male, yet the maximum safe and
effective angles maintain at the same level for both. While not addressing soft tissue
coverage, surgical exposure, or reduction effects of the fracture during surgeries, this 3D
measurement study of safe screw pathways based on the reconstruction of pelvis
provides a solid reference for the treatment of acetabular fractures.
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Author Contributions
Xiaoxi Ji designed the study, participated in the measurements of parameters, analyzed the data and drafted the manuscript. Chun Bi and Yuchen Jiang participated in the measurements. Fang Wang, Dongmei Wang and Min Zhu carried out the literature research. Qiugen Wang participated in the design and coordination of the study and reviewed the manuscript. All authors read and approved the final manuscript.

Conflict of interest
The authors declare no conflict of interest.


**Figure legends**

Figure 1 Five acetabular area sections were obtained by intersecting five normal planes perpendicular to the curve and the pelvis.

Figure 2 The five sections were recorded as section 1, 2, 3, 4, and 5 from the pubic tubercle to the sacroiliac joint direction.

Figure 3 To section 1 and 5, the distance between the screw entrance point and the intersection point was measured and recorded as the depth of the screw, $d$.

Figure 4 To section 2 and 3, the line tangent to the expanded arc through the screw entrance point was recorded as the depth of the screw, $d_1$. The angle between the tangent line and the normal plane was recorded as $\alpha$. The angle between the line connecting the screw entrance point and the intersection point and the normal plane was recorded as $\beta$.

Figure 5 To section 4, the depth of screw $d_1$ and the angle $\alpha$ were measured with the method same as section 2 and 3. The line tangent to the arc of quadrilateral surface through the screw entrance was recorded as the depth of screw, $d_2$. The angle between the tangent line and the normal plane was recorded as $\beta$. 
Table legends

Table 1 Comparison between male and female