Superior border of the arcuate line: Three dimension reconstruction and digital measurements of the fixation route for pelvic and acetabular fractures

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Received: 17 December 2012 / Accepted: 18 January 2013 / Published online: 6 February 2013
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Abstract

Purpose To obtain a series of parameters describing the shape and bone thickness of the fixation route along the superior border of the arcuate line, so as to provide references for pelvic and acetabular surgery and design pelvic anatomic internal fixators.

Method A total of 175 complete pelvic computed tomography (CT) scans of normal adult pelvises 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 divided into 11 equal parts. The total length of the curve, the radius of curvature, and the bone thickness at each decile point were all measured. The position of the pelvic inlet, the anterior and posterior sagittal diameter were measured.

Results The radius of curvature at each decile point were 29.18 ± 15.53 , 55.27 ± 29.48 , 43.04 ± 14.42 , 59.62 ± 21.02 , 91.67 ± 52.01 , 78.9 ± 38.66 , 75.76 ± 25.87 , 61.75 ± 16.68 ,

54.62 ± 14.88 , and 43.61 ± 19.10 mm, respectively. The anterior and posterior sagittal diameter of the pelvic inlet was 66.01 ± 9.15 and 41.36 ± 8.19 mm, respectively. For all groups divided by the ratio of the posterior and the anterior sagittal diameter, the decile points 1, 3, and 10 had smaller radii of curvature than the before and after points, respectively.

Conclusions The curve of the fixation route along superior border of arcuate line has a relatively greater bending degree at the pubic tubercle, iliopubic eminence and close to the sacroiliac joint. With the transition of the pelvic inlet shape from android to gynecoid and platypelloid type, the bone surface at the iliopubic eminence becomes flatter. Pelvic and acetabular surgery could be more accurate by referring to the previous key bending points and the change of the pelvic inlet shape.

Introduction

Compared to a long bone, the shape of the pelvis is more complex and irregular. Thus, plate shaping of the pelvis during surgery is not perfect. In fact, repeatedly shaping the reconstruction plate during the operation is more likely to result in prolonged operation time, breakage of the internal fixator, and loss of stage I reduction due to the mismatch of the shape of implant and pelvis. All of the problems mentioned above increase the risk of the operation and the incidence of complications [1–3]. For rotationally unstable pelvic fractures and peri-anterior column fractures of the acetabulum (including fractures of the anterior wall, anterior column, transverse fractures, T-shaped fractures, and fractures of the anterior column or anterior wall associated with

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a hemi-transverse fracture), the incidence is relatively high (52.4 % and 47.5 %, respectively) [4, 5]. The effects of the reduction and fixation of the fractures directly determine the occurrence of postoperative complications and the patient's quality of life [6]. The two groups of fractures usually result in ruptures of the pelvic anterior ring, especially of the arcuate line. Therefore, to fix the aforementioned fractures, the inferior border of the iliac fossa and its forward extension are commonly chosen as areas to place the reconstruction plate [7]. This region is considered an ideal implant location, because it provides clear surgical exposure, a flat bone surface, and relatively thick bone tissue. According to the specific fracture type, the reconstruction plate can extend along the pubic tubercle, pubis pecten, iliopubic eminence, arcuate line, or it may approach the sacroiliac joint. Letournel et al. reported that fixing the anterior wall, anterior column, or a fracture that extended out of the hip joint, could be accomplished by positioning a long reconstruction plate along the pubis pecten to the arcuate line [8]. Jakob et al. treated anterior column fractures of the acetabulum and pelvic ring fractures by placing the plate along the superior ramus of the pubis or the iliopubic eminence to the arcuate line. By doing this, the authors achieved satisfactory anatomic reduction [9]. At present, due to the complex and irregular shape of the pelvis compared to a long bone, and the multi-plane and multi-radian fixation route in 3D, no anatomical data for the fixation route along the superior border of the arcuate line is currently available, which results in an inefficient and ineffective plate shaping procedure. 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 [8, 10, 11]. Thus, the first hypothesis was raised to obtain an optimized plate shape of pelvic fixator by digital 3D anatomical measurements, which eliminates the prolonged operation time, breakage of the fixator and loss of stage I reduction.

Unlike other human bones, the pelvic shape appears markedly different between males and females. For the female pelvis alone, there are four different shapes, which are termed gynecoid, android, platypelloid and anthropoid [12, 13]. Although finding a perfect match for each pelvic shape can offer the maximal anatomical matches between the internal fixator and the pelvis, it is

relatively unrealistic and costly for industrial manufacture. Differences among pelvic shapes are related to the changes of the pelvic inlet shape; in particular, to the ratio of the posterior sagittal diameter to the anterior sagittal diameter (D_{Sp}/D_{Sa}) and the ratio of the transverse diameter to the sagittal diameter (D_T/D_S). With the increase of D_{Sp}/D_{Sa} and D_T/D_S , the pelvic inlet shape transitions from the heart-shape of the android type to the approximately round, elliptical shape of the gynecoid and platypelloid types [14]. Hence, the second hypothesis was raised to find the relationship between D_{Sp}/D_{Sa} , D_T/D_S and the shape of the superior border of the arcuate line, which could be used as a base on which to estimate the general shape of the internal fixator by pelvic type.

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 a series of parameters describing the shape and bone thickness of the fixation route along the superior border of the arcuate line to the pubic tubercle, and find the relation between D_{Sp}/D_{Sa} , D_T/D_S and the shape of the superior border of the arcuate line; and finally, to provide a good reference for pelvic and acetabular surgeries and the design of pelvic anatomical internal fixators at the superior border of the arcuate line.

Patients and methods

Samples and equipment

We collected the computed tomography scans from outpatients with varicose veins of the lower limb, who needed enhanced computed tomography scan (CT scan) from pelvis to feet. Each patient with pelvic deformity, trauma, tumor and other diseases on CT scans and in their history was eliminated. From December 2009 to November 2010, 175 complete pelvic computed tomography scans of unrelated ethnic Han Chinese adults (mean age 61.0 [22–91] years; 105 men, 70 women) were collected from the medical image database of the department of radiology of a large comprehensive hospital. The age distribution of all 175 patients is seen in Table 1. During CT scanning, patients kept the standard

Table 1 Age distribution of all 175 patients

	21–30 yrs	31–40 yrs	41–50 yrs	51–60 yrs	61–70 yrs	71–80 yrs	≥ 81 yrs
Male	4	5	5	16	17	9	5
Female	2	11	13	30	24	21	13
Total	6	16	18	46	41	30	18

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 that was collected from outpatients, 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 Geomagic 10, and the mechanical design software Unigraphics NX. The study was approved by the Review Board of Shanghai First People's Hospital.

Measurement of parameters

Each volunteer'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 Geomagic 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 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. 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, several points were picked at the cortical surface, 10 mm lateral to the pelvic brim in the superior border of the arcuate line, to draw

the space curve of the bone surface. By intersecting extrusion, the required measurement model and the anatomical curve were extracted.

The measurement model and the anatomical curve were imported to UG in the STL and IGES format. Thus, the total length of the curve (L) can be measured. By dividing the curve into eleven equal parts, the radius of curvature at each decile point, $r_1, r_2, \dots, r_{10}$, and the bone thickness of each decile point, $d_1, d_2, \dots, d_{10}$, were achieved from front to back. The curve section was divided into front-acetabular, acetabular, and post-acetabular areas by the location of the acetabulum, and the thinnest bone regions of the three parts, D_1, D_2, D_3 , were measured (Fig. 1).

The pelvis was imported to the Imageware 12.0 software as a mesh model in the STL format. After being rotated to the position of the pelvic inlet, and compressing the pelvis to the inlet plane as with X-ray films, the transverse diameter of the pelvic inlet D_T (the widest distance), the sagittal diameter D_S (the distance from the anterior border of the sacral promontory to the posterior border of the pubic symphysis), the anterior sagittal diameter D_{Sa} , and the posterior sagittal diameter D_{Sp} could all be measured (Fig. 2). Finally, the ratio of the posterior sagittal diameter to the anterior sagittal diameter (D_{Sp}/D_{Sa}) and the ratio of the transverse diameter to the sagittal diameter (D_T/D_S) were calculated.

Statistical analysis

The data were expressed as mean $\pm$ 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 pelvis were categorized into seven groups by D_{Sp}/D_{Sa} (≤ 0.40 , $0.41-0.50$, $0.51-0.60$, $0.61-0.70$, $0.71-0.80$, $0.81-0.90$, ≥ 0.90), and the relationship between the radius of curvature and the decile point was analyzed. Each

Fig. 1 By dividing the curve into ten equal parts, the radius of curvature at each decile point, $r_1, r_2, \dots, r_{10}$, and the bone thickness of each decile point, $d_1, d_2, \dots, d_{10}$, were achieved from front to back. The thinnest bone regions of the three parts, D_1, D_2, D_3 , were measured

Fig. 2 In the position of the pelvic inlet, just like the inlet X-ray plane, the transverse diameter of pelvic inlet D_T , the sagittal diameter D_S , the anterior sagittal diameter D_{Sa} , and the posterior sagittal diameter D_{Sp} were measured

group was tested and showed normal distributed. For each group, we compared the mean values of the radius of curvature between two adjacent points from decile point 1 to 10 with the T test.

Results

The radius and the bone thickness of curvature at each decile point are seen in Table 2 and Table 3. The thickness of the front-acetabular, acetabular, and post-acetabular areas were 11.67 ± 2.94 , 13.97 ± 3.36 , and 28.21 ± 3.46 mm, respectively (Table 4). The transverse diameter, the sagittal diameter, the anterior sagittal diameter, and the posterior sagittal diameter of the pelvic inlet were 124.14 ± 11.69 , 107.38 ± 13.51 , 66.01 ± 9.15 , and 41.36 ± 8.19 mm, respectively (Table 5).

The comparisons between the mean values of the radius of curvature between two adjacent points from decile point 1 to 10 showed that the mean value of decile point 1 was smaller than point 2, which of point 3 was smaller than point 2 and 4, point 10 smaller than point 9. And there were significant differences between the mean values of the radius of curvature at decile points 1 and 2; 2 and 3; 3 and 4; and 9 and 10 ($p < 0.05$) (Table 6). Hence, for all groups divided

by D_{Sp}/D_{Sa} , the decile points 1, 3, and 10 had smaller radii of curvature than the before and after points, respectively (Fig. 3). The radius of curvature at decile point 3 showed an obvious rising trend with the rising of D_{Sp}/D_{Sa} . However, the radii of curvature at decile points 1 and 10 had no obvious trend (Fig. 4).

By dividing the whole pelvis by D_T/D_S and repeating the work above, we tried to describe the general situation of the radius of curvature at each decile point for different D_T/D_S groups. However, we did not identify any obvious trends.

Discussion

When dealing with peri-anterior column fractures of the acetabulum (including fractures of the anterior wall, anterior column, transverse fractures, T-shaped fractures, fractures of the anterior column or anterior wall associated with a hemi-transverse fracture, and fractures of both columns) and rotationally unstable pelvic fractures, the superior border of the arcuate line, including its forward extension, is commonly chosen as the region to place the reconstruction plate. According to the specific fracture type, the reconstruction plate can extend along the pubic tubercle, pubis pecten,

Table 2 The radius of curvature at each decile point

	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}
Total	29.18 ± 15.53	53.29 ± 16.26	43.04 ± 14.42	59.62 ± 21.02	93.67 ± 13.01	76.9 ± 18.66	75.76 ± 15.87	61.75 ± 16.68	54.62 ± 14.88	43.61 ± 19.10
Male	24.51 ± 10.86	48.86 ± 20.84	35.96 ± 9.38	59.54 ± 22.92	87.2 ± 16.15	72.00 ± 16.91	77.07 ± 19.23	61.93 ± 18.31	51.68 ± 14.05	42.17 ± 19.64
Female	36.10 ± 12.33	60.13 ± 17.30	53.55 ± 14.24	59.72 ± 18.07	92.57 ± 18.69	97.17 ± 18.37	73.84 ± 10.05	61.48 ± 14.01	59.01 ± 15.09	45.77 ± 18.20
P Value	0.0002	0.0007	0.0001	0.955	0.467	0.001	0.423	0.860	0.001	0.226

Table 3 The bone thickness of each decile point

	d ₁	d ₂	d ₃	d ₄	d ₅	d ₆	d ₇	d ₈	d ₉	d ₁₀
Total (mm)	21.78± 9.48	14.14± 5.07	12.9± 2.96	23.53± 7.18	18.8±7.61	15.55± 3.48	29.91± 14.78	46.03± 9.43	33.12± 6.15	30.41± 4.06
Male (mm)	23.24± 9.78	14.93± 4.53	13.92± 2.75	25.93± 7.13	19.09± 5.16	17.09± 3.05	28.49± 13.75	49.38± 9.16	35.77± 6.05	31.28± 4.12
Female (mm)	19.61± 8.63	12.97± 5.63	11.38± 2.62	19.95± 5.65	18.38± 10.26	13.27± 2.76	32.03± 16.06	41.07± 7.48	29.19± 3.75	29.13± 3.63
P Value	0.013	0.012	0.0008	0.0006	0.547	0.0003	0.134	0.0003	0.0005	0.001

iliopubic eminence, arcuate line, or it may approach the sacroiliac joint. This area is considered an ideal implant location, because it provides clear surgical exposure, flat bone surface, and relatively thick bone tissue [15–17]. No anatomical data for the fixation route along the superior border of the arcuate line is currently available, which is associated with prolonged operation times due to shaping the reconstruction plate during the surgery, breakage of the internal fixator due to being repeatedly bent, and loss of stage I reduction due to the mismatch in the shape of implant and pelvis. All of these possibilities increase the risk of the operation and the incidence of complications [18]. The two hypotheses of this study are to obtain an optimized plate shape of pelvic fixator by digital 3D anatomical measurements, which eliminates the prolonged operation time, breakage of the fixator and loss of stage I reduction, and to find the relation between D_{Sp}/D_{Sa} , D_T/D_S and the shape of the superior border of the arcuate line, which could be used as a base on which to estimate the general shape of the internal fixator by pelvic type.

3D measurement of the fixation route along the superior border of the arcuate line

Since the superior border of the arcuate line is often used as the position to correct rotationally unstable pelvic fractures and peri-anterior column acetabular fractures, it is of great importance to analyze its 3D shape. There is no anatomical data for this fixation route currently available. This study built 3D digital models based on large samples of normal adult pelvic high resolution CT images, measured crucial parameters of the fixation route along the superior border of the arcuate line, discovered critical anatomical positions for

shaping the reconstruction plate, and provided reference for the design of pelvic anatomical internal fixators at this area.

According to the results of Table 1, the deviation of the data was relatively extent. After eliminating the miscalculation, we think it was caused by the manual operation during the process of picking the cortical surface points to draw the space curve. As the surface of the pelvis is fluctuating and the value of the radius of curvature is sensitive, the value is affected by the error of the manual operation.

By combining each decile point's bending, which can be derived from the radius of curvature, with the actual rising or sinking status of the pelvic surface, it is possible to achieve better plate-pelvis matching results. The total length of the curve (male: 143.47±10.22 mm, female: 151.62±9.67 mm, $P<0.001$) helps in choosing the length of the plate. The bone thickness of each decile point provides reference for the drilling depth and the screw length, which is important in terms of avoiding blood vessel and nerve injuries. The thinnest bone region of the acetabulum area (male: 15.37±3.08 mm, female: 11.89±2.60 mm, $P<0.001$) contributes to the accuracy of acetabular screw placement, preventing the screw from penetrating into the acetabulum and causing severe complications. The diameters of the pelvic inlet and related ratio calculations reveal the differences among different pelvic shapes at the fixation route along the superior border of the arcuate line. They also assist in shaping the plates more quickly and more accurately. Furthermore, the anatomical data achieved in this study provides reference for the design of pelvic anatomical internal fixators in this area. All samples in this study were healthy adults. Epiphysis for all cases is closed. Therefore, neither age nor changes in the size of the pelvis were considered. Some parameters were statistically significantly

Table 4 The thinnest bone thickness of the front-acetabular, acetabular, and post-acetabular areas, the total length of the curvature

	D ₁	D ₂	D ₃	L
Total (mm)	11.67±2.94	13.97±3.36	28.21±3.46	146.75±10.75
Male (mm)	12.64±2.84	15.37±3.08	29.14±3.69	143.47±10.22
Female (mm)	10.22±2.48	11.89±2.60	26.84±2.54	151.62±9.67
P Value	0.0006	0.0002	0.0005	0.0008

Table 5 The parameters of the pelvic inlet

	D _T	D _S	D _{Sa}	D _{Sp}	D _{Sp} /D _{Sa}	D _T /D _S
Total (mm)	124.14±11.69	107.38±13.51	66.01±9.15	41.36±8.19	0.64±0.14	1.17±0.17
Male (mm)	119.62±11.60	103.01±11.69	65.01±8.82	38.00±6.61	0.59±0.13	1.18±0.18
Female (mm)	130.85±8.08	113.96±13.48	67.53±9.48	46.43±7.77	0.70±0.14	1.16±0.16
P Value	0.0003	0.0005	0.076	0.0002	0.0008	0.623

different between males and females: D_T (male: 119.62±11.60 mm, female: 130.85±8.08 mm, $P<0.001$), D_S (male: 103.01±11.69 mm, female: 113.96±13.48 mm, $P<0.001$), D_{Sp} (male: 38.00±6.61 mm, female: 46.43±7.77 mm, $P<0.001$) and D_{Sp}/D_{Sa} (male: 0.59±0.13 mm, female: 0.70±0.14 mm, $P<0.001$).

To understand the general direction and important turning points of the fixation route for different inlet shapes, we divided the entire pelvis into groups by D_{Sp}/D_{Sa}, and analyzed the radius of curvature at each decile point for each group. For any group divided by D_{Sp}/D_{Sa}, the decile points 1, 3, and 10 had smaller radii of curvature than the before and after points, respectively. Relating the aforementioned decile points to anatomical positions, we found that for all of the pelvic inlets of different shapes, the curve has a relatively greater bending degree at the pubic tubercle, iliopubic eminence, and near the sacroiliac joint. For all other locations, it is relatively flat. In clinical practice, the bending of the plate is the vital and complex step of pelvic and acetabular surgery, which is partly the reason why the learning curve of these operations is quite prolonged [19, 20]. According to this study, more bending should be conducted at the pubic tubercle, iliopubic eminence and near the sacroiliac joint during pelvic and acetabular surgery. More comparisons between the key bending points and the adjacent bone surface need to be taken to bend the plate fewer times. Hence, the time of shaping the reconstruction plate and the breakage of the internal fixator could be reduced by accurate and adequate plate bending.

The relation between the shapes of the pelvic inlet and the superior border of the arcuate line:

Unlike other human bones, the pelvic shape appears markedly different between males and females. Even for the

female pelvis alone, there are four different shapes, which are termed gynecoid, android, platypelloid and anthropoid [10]. Differences among pelvic shapes are related to the changes of the pelvic inlet shape, in particular, to the ratio of the posterior sagittal diameter to the anterior sagittal diameter (D_{Sp}/D_{Sa}) and the ratio of the transverse diameter to the sagittal diameter (D_T/D_S). With the increase of D_{Sp}/D_{Sa} and D_T/D_S, the pelvic inlet shape transitions from the heart-shape of the android type to the approximately round, elliptical shape of the gynecoid and platypelloid types. In this study, we analyzed the trends of the radii of curvature at decile points 1, 3, and 10 with the change of D_{Sp}/D_{Sa}. We found that the radius of curvature at decile point 3 showed an obvious rising trend with the rising of D_{Sp}/D_{Sa}. However, the radii of curvature at decile points 1 and 10 had no obvious trends. It could be interpreted as with the transition of the pelvic inlet shape from android type to gynecoid and platypelloid types, the bone surface at the iliopubic eminence becomes flatter, but there is no obvious trend either at the pubic tubercle or close to the sacroiliac joint. In addition, we analyzed the trend of the radius of curvature for eleven decile points with different D_T/D_S. This did not reveal any obvious trends, which means it is still not reliable to provide references for the fixation route along the superior border of the arcuate line by the transition of the pelvic inlet shape. In brief, more plate bending should be conducted in gynecoid pelvis than in other types during pelvic and acetabular surgeries.

Safe paths for screw placement on the anterior column of the acetabulum:

When fixing acetabular fractures through anterior approaches like the ilioinguinal and stoppa approaches, lack of visualization of the hip joint might lead to improper screw direction or

Table 6 The significance test of difference between the mean values of the radius of curvature at decile points 1 and 2; 2 and 3; 3 and 4; and 9 and 10

	D _{Sp} /D _{Sa}						
	≤ 0.40	0.41–0.50	0.51–0.60	0.61–0.70	0.71–0.80	0.81–0.90	≥ 0.90
P Value (P1–P2)	0.015	0.0002	0.0005	0.0002	0.0001	0.003	0.013
P Value (P2–P3)	0.028	0.046	0.041	0.030	0.033	0.042	0.013
P Value (P3–P4)	0.001	0.0002	0.0003	0.0001	0.0006	0.0002	0.035
P Value (P9–P10)	0.014	0.001	0.030	0.001	0.011	0.028	0.018

Fig. 3 For any group divided by D_{Sp}/D_{Sa} , the decile points 1, 3, and 10 have smaller radii of curvature than the before and after points, respectively

position. The resulting screw penetration into the hip joint might bring future chondrolysis and osteoarthritis. Previous authors have reported several methods to prevent this severe complication, including intra-operative radiographs or fluoroscopy and auscultation of the hip with motion in a quiet room, which increase the operation time and trauma. Hence, for accurate screw placement, it is imperative to understand the unique 3D structure of the anterior column of the acetabulum [21, 22]. Although there are few quantitative anatomic data on the technique of plate-screw fixation of the anterior column of the acetabulum, some authors have proposed ways to avoid this complication based on the cross-section of the anterior column. These include: (1) Use of a long screw. Owing to the 6–12 mm thick bone tissue between the surface of the hip joint and the medial quadrilateral surface, a screw with direction parallel to the quadrilateral surface will not penetrate into the hip joint. However, due to

the restriction of the entry point, this method is suitable for simple long screw fixation only and not for plate-screw fixation. (2) Use of a short screw. The bone tissue between the pelvic brim and the hip joint surface is more than 12.0 mm. In consequence, a screw with any angle will not penetrate into the hip joint as long as the length of the screw is shorter than 12.0 mm. However, the strength of fixation with screws shorter than 12.0 mm at the anterior column needs to be validated. (3) Insert the screw at a certain angle. At the entry point 1.0 cm away from the pelvic brim, if the direction of the screw is pointing to the quadrilateral surface and greater than 20° , the screw can be kept away from the hip joint and have enough length [22, 23].

This study transected the anterior column of the acetabulum perpendicularly to the bone surface at the fixation route along the superior border of the arcuate line, and measured the minimum thickness of the acetabular area, which is considered to be a safe path for screw placement

Fig. 4 The radius of curvature at decile point 3 showed an obvious rising trend with the rising of D_{Sp}/D_{Sa} , while the radii of curvature at decile points 1 and 10 had no obvious trend

on the anterior column. The results showed that a screw perpendicular to the bone surface would not penetrate into the hip joint if it were shorter than 14 mm. Compared with the three aforementioned methods, this study has found a practical solution for plate-screw fixation at this region. However, it still needs to be improved upon.

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 that expands the analysis, including these parameters.

Conclusion

By digital reconstruction and 3D measurement of a large sample of normal adult pelvic CT scans, this study obtained a series of parameters describing the shape and bone thickness of the fixation route along the superior border of the arcuate line to the pubic tubercle, the bone thickness of the acetabular area, and the relative diameters of the pelvic inlet. We analyzed the differences between male and female, discovered the key bending points of the shape of the internal fixator, discussed the relationship between the pelvic inlet shape and the internal fixator shape, and provided references for a safe path for screw placement on the anterior column of the acetabulum. While not addressing soft tissue coverage, surgical exposure, or reduction effects of the fracture during the operation, this 3D measurement study based on the reconstruction of pelvic bone tissue provides a solid reference for clinical applications.

Acknowledgments This work is supported by following funds: National Natural Science Foundation of China, Grant number: 81272002; Translational Medicine Research Foundation of Shanghai Jiaotong University, Grant number: ZHYXXM20110001; Research Foundation of Shanghai Health Bureau, Grant number: 2010QJ038A; Research Foundation of Shanghai Science and Technology Commission, Grant number: 114119a2400; Research Foundation of Songjiang Health Bureau, Grant number: 2011LX14. The authors thank Prof. Ruishan Dang and Chentao Wang, Qinyi Wang for their assistance in the digital measurement and use of software.

Author contributions Xiaoxi Ji participated in the measurements of parameters, analyzed the data and drafted the manuscript. Fang Wang and Dongmei Wang carried out the study design and helped to draft the manuscript. Fan Li recruited the CT scans with Jie Zhang and carried out the literature research. Xiaoqin Li and Yunlong Su participated in the measurements of parameters. 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.

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