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Defining a Safety Margin for Labral Suture Anchor Insertion Using the Acetabular Rim Angle

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Background: Suture anchors are commonly used to reattach a torn labrum to the acetabular rim. The acetabular rim anatomy is not uniform, and the safety margin for inserting suture anchors is unknown. The acetabular rim angle is an anatomic measurement that is indicative of the safety margin for inserting suture anchors.

Purpose: To investigate the acetabular rim angle as a function of clock position, to evaluate the effect of drill depth on the acetabular rim angle, and to evaluate the effect of rim trimming on the acetabular rim angle.

Study Design: Descriptive laboratory study.

Methods: Three-dimensional acetabular models were reconstructed from computed tomography scans of 20 nonpaired cadaveric hip specimens, and the acetabular rim angle, which quantifies the angle between the subchondral margin and the outer cortex of the acetabulum, was measured from the 8- to 4-o'clock positions. At each position, the acetabular rim angle was measured for 5 drill depths (10, 12.5, 15, 20, and 25 mm) to simulate different lengths of suture anchors or drill bit depths on the acetabular rim angle. To simulate rim trimming, the acetabular rim angle was measured at the points that would become the suture anchor insertion points after 2.5- and 5-mm rim trimming.

Results: Clock position, drill depth, and rim trimming all had significant effects on the acetabular rim angle ($P < .0001$). The acetabular rim angle was largest at the 2-o'clock and smallest at the 3-o'clock position. Greater drill depths provided smaller acetabular rim angles, whereas rim trimming provided larger acetabular rim angles.

Conclusion: The acetabular rim angle varied significantly as a function of the location on the acetabular rim. A shorter drill depth and a greater amount of rim trimming provided a larger acetabular rim angle.

Clinical Relevance: Surgeons should be aware of the acetabular rim variations, especially in the anterosuperior quadrant, as well as the effects of drill depth and rim trimming, when selecting the optimal insertion angle for suture anchor placement to avoid articular cartilage penetration. The acetabular safety angle was smallest at the 3-o'clock position. Therefore, extra care must be taken when drilling or inserting anchors around the 3-o'clock position.

Keywords: acetabular rim; labral tear; labral repair; suture anchor

Acetabular labral tears are a common cause of hip pain[3,11] and contribute to the development of osteoarthritis of the hip.[15] There are many conditions that have been reported to cause labral tears, such as trauma, femoroacetabular impingement, psoas impingement, capsular laxity/hip hypermobility, developmental dysplasia of the hip, and hip degeneration.[11,19] The anterosuperior quadrant of the acetabular rim is most commonly involved; however, tear locations can be varied.[1,13,15]

Biomechanical studies have reported the importance of the labrum in enhancing hip joint stability, maintaining the suction seal effect, and decreasing cartilage consolidation.[4-6] A recent study using Tesla magnetic resonance scans[7] demonstrated articular cartilage strain increased after labral resection when compared with labral repair.[8] Clinical studies have demonstrated improved results in patients treated with labral refixation compared with those with labral debridement.[2,14,17]

A suture anchor is most commonly used for reattaching the torn labrum to the acetabular rim.[11,16,18] An appropriate angle of suture anchor insertion is required to obtain

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stable fixation and avoid penetration of the articular cartilage.[11] An improved understanding of acetabular rim anatomy will facilitate safe insertion of suture anchors. This can be evaluated by measuring the acetabular rim angle, which quantifies the angle between the subchondral margin and the outer cortex of the acetabulum. A larger acetabular rim angle would provide a higher safety margin for inserting the suture anchor at that particular rim position.

The purpose of this study was to demonstrate the usefulness of the acetabular rim angle as an anatomic measurement of the safety margin for suture anchor insertion. The acetabular rim angle was measured in 3-dimensional (3D) models of acetabuli from the 8-o'clock position posteriorly to the 4-o'clock position anteriorly. The effects of drill depth and rim trimming on the acetabular rim angle were evaluated. It was hypothesized that the acetabular rim angle at each location of the acetabular rim was different. In addition, a greater drilling depth would provide a smaller acetabular rim angle, whereas rim trimming would provide larger acetabular rim angles.

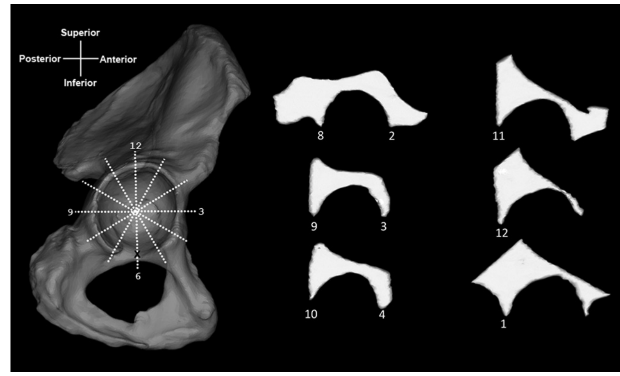

Figure 1. The 3-dimensional reconstructed model of the pelvis and acetabular slices at each clock position. The 6-o'clock position was located at the middle of the acetabular notch (X). The numbers indicate clock positions.

METHODS

Computed tomography scans of 23 nonpaired fresh-frozen cadaveric hip specimens were obtained using an Aquilion 64 (Toshiba America Medical Systems, Tustin, California). The sequence of images from the scan, representing axial slices of 0.5-mm thickness with a resolution of 512×512 pixels (voxels approximately $0.7 \times 0.7 \times 0.5$ mm^3), was obtained using standard 120 kVp and 250 mAs techniques with sharp-bone CT reconstruction. Three specimens were excluded because 2 hips had severe osteoarthritis and 1 hip had a rim fracture. This left 20 hips (mean age, 72 ± 14 years; range, 53-97 years; 11 men, 9 women; 11 left, 9 right) available for measurements.

The CT data of each hip specimen were imported into Mimics (Materialise, Leuven, Belgium) to reconstruct a 3D geometric model of each acetabulum. The acetabular rim has a wave-like outline with 3 prominences and 2 depressions irrespective of gender.[12] The tips of the anterosuperior, the anteroinferior, and the posteroinferior rim prominences were used to define the acetabular opening plane[12] that was used for positioning the acetabular models. Locations along the acetabular rim were given in a clock face system (Figure 1) commonly used in arthroscopic surgery[20] and anatomic studies of the acetabulum.[12] The 6-o'clock position was located at the midpoint of the acetabular notch,[12] which corresponded to the middle of the transverse acetabular ligament.[20] All data on the left-sided models were mirrored and presented as right-side models. A 20-mm-diameter sphere was positioned at the center of the femoral head and used as the reference length for the measurements.

Each acetabulum model was resliced (digitally sectioned) perpendicular to the acetabular opening plane from the 8-o'clock position posteriorly to the 4-o'clock position anteriorly (Figure 1). The images of all slices were used to measure the acetabular rim angle using tpsDig freeware (F.J. Rohlf, Department of Ecology and Evolution, State University of New York at Stony Brook, Stony Brook, New York). The acetabular rim angle was defined as the angle between 2 straight lines (vectors) of a fixed length that started at the acetabular rim and touched the subchondral bone margin on one side and the outer cortex of the acetabulum on the other side (Figure 2). The magnitude of the measured angle would thus depend on the starting point (rim trimming), the vectors' lengths (drill depth), and bony anatomy (clock position). At each clock position, 5 vector lengths (10, 12.5, 15, 20, and 25 mm) were employed to investigate the effect of different drill depths or lengths of suture anchors. To investigate the effect of rim trimming, 3 points of measurement were used representing the point of suture anchor insertion after rim trimming: (1) the tip of the acetabular rim (no trimming), (2) 2.5 mm from the tip of the acetabular rim measured perpendicular to the acetabular opening plane and 3 mm from the subchondral bone margin measured parallel to the acetabular opening plane, and (3) 5 mm from the tip of the acetabular rim measured perpendicular to the acetabular opening plane and 3 mm from the subchondral bone margin measured parallel to the acetabular opening plane (Figure 3).

Reliability of measurement was obtained by 2 observers who performed 2 repeated measurements (from the 3D model orientation to angle measurements) with a 4-week interval between measurements. These included 90 measurements in 10 pelvic models with randomly selected variables (clock positions, drill depths, and simulated rim trimming conditions).

Interobserver and intraobserver reliability of the measurement was evaluated by intraclass correlation coefficients (ICCs) and standard error of measurement. The mean measure ICC evaluated interobserver reliability by comparing the averages of the 2 repeated measurements. The single-measure ICC determined the intraobserver reliability of the 2 measurements by each observer. The effects of clock position, drill depth, rim trimming, and gender on

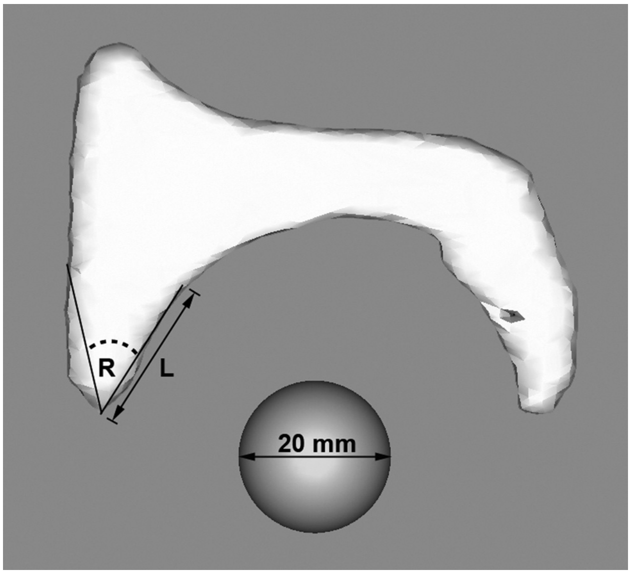

Figure 2. The acetabular rim angle (R) was created by drawing 2 straight lines (vectors) of a fixed length (L) that started at the acetabular rim and touched the subchondral bone margin on one side and the outer cortex of the acetabulum on the other side. Different angle arm lengths (L) were applied to simulate different drill depths for different lengths of suture anchors. A sphere of 20-mm diameter was reconstructed at the center of the femoral head as a reference length. In this picture, the angle arm length was 20 mm, and the left line touched the outer cortex with its tip, whereas the right line touched the subchondral bone margin with its side.

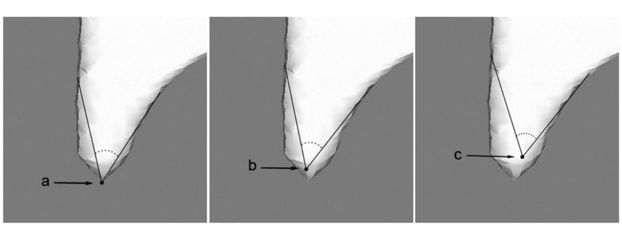

Figure 3. Three starting points of measurement were used to measure the acetabular rim angle at each clock position of the acetabular rim to evaluate the effect of rim trimming: (a) the tip of the acetabular rim (no trimming), (b) 2.5 mm from the tip of the acetabular rim measured perpendicular to the acetabular opening plane and 3 mm from the subchondral bone margin measured parallel to the acetabular opening plane, and (c) 5 mm from the tip of the acetabular rim measured perpendicular to the acetabular opening plane and 3 mm from the subchondral bone margin measured parallel to the acetabular opening plane.

the acetabular rim angle were assessed by multivariate analysis. Statistical significance was assumed when $P < .05$. SPSS software (SPSS Inc, Chicago, Illinois) was used for statistical calculation.

TABLE 1
Reliability of the Measurement of the Acetabular Rim Angle[a]

	ICC	95% CI	SEM, deg
Interobserver	0.994	0.990-0.996	2.5
Intraobserver			
Observer 1	0.984	0.977-0.990	3.0
Observer 2	0.967	0.950-0.978	4.5

[a]CI, confidence interval; ICC, intraclass correlation coefficient; SEM, standard error of measurement.

RESULTS

Clock position on the acetabular rim, drill depth, and simulated rim trimming each had a significant effect on the acetabular rim angle ($P < .0001$), whereas there was no significant difference between male and female acetabuli. Interobserver and intraobserver reliability was high (ICC > 0.967), and the standard error of measurement was 4.5° or lower (Table 1).

The acetabular rim angle at the tip of the acetabular rim was largest at the 2-o'clock position (89.3° ± 14.3°), followed by the 8-o'clock position (74.6° ± 16.7°), and smallest at the 3-o'clock position (39.6° ± 11.9°) (Table 2). There were no significant differences in the acetabular rim angle at the posterosuperior quadrant positions (from 9 o'clock to 12 o'clock; mean difference between clock positions, <2.1°), but significant differences were found at the anterosuperior quadrant positions (from 12 o'clock to 3 o'clock; mean difference between 12 and 1 o'clock, 20.9°, $P < .0001$; 1 and 2 o'clock, 27.5°, $P < .0001$; 2 and 3 o'clock, 59.2°, $P < .0001$).

The greater drill depths provided the smaller acetabular rim angle (Figure 4). The mean reduction in acetabular rim angle was 6.3° for every 5 mm in added drill bit depth (Table 3; note that the first 2 depth increments were 2.5 mm). The acetabular rim angle became larger with simulated rim trimming (Figure 5). The mean increments of the acetabular rim angle were 12.7° for simulated rim trimming of 2.5 mm ($P < .0001$) and 22.6° for simulated rim trimming of 5 mm compared with the angle measured at the tip of the acetabular rim ($P < .0001$).

DISCUSSION

In this study, the acetabular rim angle was defined as an anatomic measurement of the safety margin for suture anchor insertion. A larger acetabular rim angle would provide a higher safety margin for inserting the suture anchor and, thus, demonstrate a lower risk for anchor penetration of the cartilage surface at that particular rim position. The acetabular rim angle was dependent on the acetabular rim location (clock position), the drill depth, and the amount of rim trimming. Large differences in the acetabular rim angle were found at the anterosuperior quadrant, where labral tears are commonly located,[1,13,15] but not in the posterosuperior quadrant of the acetabulum. The acetabular safety

TABLE 2
Acetabular Rim Angles at the Tip of the Acetabular Rim Measured With Different Drill Depths[a]

	Drill Depth, mm				
Clock Position	10	12.5	15	20	25
8	76.5 ± 16.8	74.8 ± 17.0	74.3 ± 17.1	73.8 ± 17.3	73.5 ± 17.1
9	60.7 ± 10.9	55.9 ± 10.0	52.4 ± 9.1	47.8 ± 8.9	44.5 ± 8.9
10	55.0 ± 9.5	51.6 ± 8.7	49.5 ± 7.9	46.3 ± 6.9	42.7 ± 6.3
11	51.3 ± 9.6	49.1 ± 9.2	47.7 ± 9.2	44.6 ± 8.4	42.2 ± 8.7
12	53.1 ± 9.3	49.4 ± 9.3	47.6 ± 9.4	45.7 ± 8.7	44.8 ± 8.8
1	66.9 ± 15.9	63.3 ± 16.1	61.9 ± 16.4	61.6 ± 16.3	61.5 ± 16.2
2	92.6 ± 14.1	90.5 ± 14.1	89.7 ± 13.9	89.1 ± 13.9	84.6 ± 15.5
3	50.3 ± 9.2	46.0 ± 8.6	42.2 ± 7.9	33.9 ± 7.1	25.5 ± 7.3
4	75.1 ± 12.9	68.9 ± 11.0	63.2 ± 9.7	51.0 ± 9.7	39.0 ± 13.4

[a]Data are presented in degrees (mean ± SD).

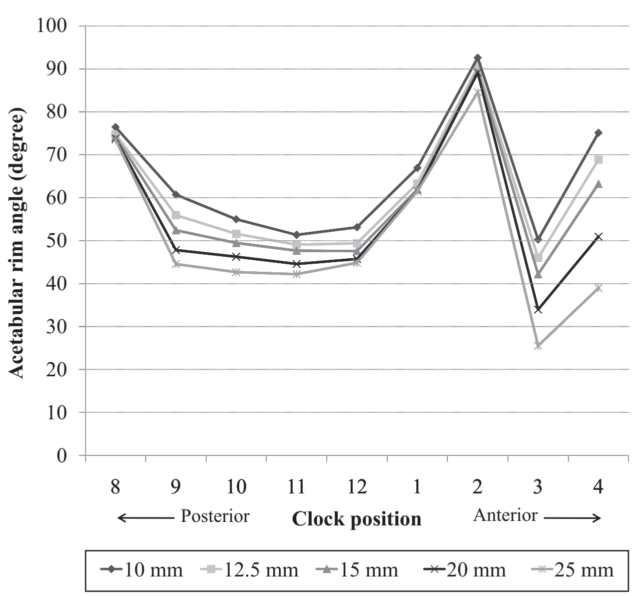

Figure 4. Acetabular rim angles as a function of clock position measured at the tip of the acetabular rim (no rim trimming) for different drill depths.

angle was smallest at the 3-o'clock position. Therefore, extra care must be taken when drilling or inserting anchors around the 3-o'clock position. Greater drill depths provided smaller acetabular rim angles, whereas rim trimming provided larger acetabular rim angles.

Köhnlein et al[12] evaluated the spatial acetabular rim profile in 66 acetabuli using plaster molds. The acetabular opening plane and clock face orientation were also employed in their measurements. The acetabular rim profile had a constant and regular wave-like outline without gender differences. There were 3 prominences: anterosuperiorly (at 1:50, hour:minute), anteroinferiorly (at 4:40), and posteroinferiorly (at 7:50).[12] In our study, these 3 positions corresponded closely to areas of high acetabular rim angle. The 2-o'clock position, which had the highest acetabular rim angle, was close to the anterior inferior iliac spine,

TABLE 3
Mean Differences of the Acetabular Rim Angles Measured With Different Drill Depths

Drill Depth, mm	Mean Differences, deg	*P*
10 and 12.5	4.9	<.0001
12.5 and 15	3.3	<.0001
15 and 20	5.3	<.0001
20 and 25	5.3	<.0001

and the 8-o'clock position was close to the ischial tuberosity (Figure 1). The 2 depressions were found at the anterior wall (at 3:20) and the posterosuperior wall (at 11:00).[12] These points also had relatively low acetabular rim angles in our study. The 3-o'clock position was the point of lowest acetabular rim angle and corresponded to the so-called psoas valley[24,25] at the anterior acetabular rim, which can also be observed during hip arthroscopy.

Hernandez and McGrath[9] assessed the safe angle for 3 suture anchor systems at the anterosuperior quadrant of 9 acetabuli. The angles were measured by overlying the drill onto the radially sectioned acetabulum (12-, 1:30-, and 3-o'clock positions) using the capsular labral insertions, 2.3 to 2.6 mm from the tip of the acetabular rim, as the points of measurement. A line drawn between the capsular labral insertions on the anterior and posterior acetabular rims was used as a reference line of angle measurement. The safe angle measured at the anterosuperior position was lower than was the superior and the anterior position, and the acetabular bone width measured parallel to that reference line was not different between these 3 locations. Their findings are different from the current study, which demonstrated significantly higher acetabular rim angle at the anterosuperior locations (1 and 2 o'clock) compared with the superior (12 o'clock) and the anterior (3 o'clock) positions. The magnitudes of the angle shown in their study were lower than those in our study because their measurement took account of the diameter of each suture anchor system.

Suture anchor systems generally have a drill bit depth greater than the length of the suture anchor for predrilling before insertion of the suture anchor. As a result, the

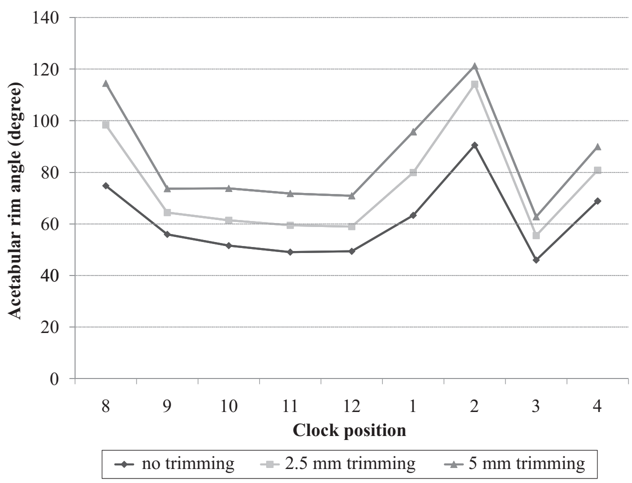

Figure 5. Acetabular rim angles as a function of clock position measured for the drill depth of 12.5 mm for the 3 simulated rim trimming conditions.

magnitude of the acetabular rim angle would be determined by the length of the drill bit. This study elucidated the advantage of a shorter suture anchor system on the acetabular rim angle that should be taken into account in implant designs.

Rim trimming, also called acetabuloplasty, is performed to create a bleeding bed of bone to facilitate labral healing to the acetabular rim after refixation[7] and for the treatment of pincer impingement.[18] The amount of rim trimming is dictated by the severity of pincer impingement, which may be quantified by the degree of the center edge angle and the crossover sign.[21,22] This study demonstrated an additional advantage of rim trimming in that it increases the acetabular rim angle.

Application of the acetabular opening plane in this study provided consistent orientation for repositioning and reslicing the 3D acetabular model. It was also used as the reference to locate the points of measurement in simulated rim trimming conditions. This measurement technique had excellent interobserver and intraobserver reliability.[10]

There were some limitations in this study. The hip specimens used in this study did not include hips with significant morphologic abnormalities such as dysplastic hips. However, appropriate plain radiographs could not be obtained because the hemipelvis specimens could not be positioned in the desired position for radiographic measurement of the acetabular rim profile.[23] Consequently, osteoarthritis grading and the acetabular rim profile (such as center edge angle, Tonnis angle, crossover sign, etc) were not obtained. However, CT scans and 3D models were available for the specimens, and no significant abnormalities were observed. The acetabular rim angle presented in this study was measured in 1 plane only, which is perpendicular to the acetabular opening plane at the site of insertion and angled radially toward the joint center. However, during hip arthroscopy, the drilling angle can be constrained by arthroscopic portal positions and the surrounding bony or soft tissue structures. Therefore, in vivo insertion angles will not always be at the standardized angles used in this study. Variability in acetabular rim angle may occur as a result of altered insertion angles. The methodology used in this study can be modified to include in vivo insertion angles achievable through various portal locations. Finally, the measurement of the acetabular rim angle did not include the width of the suture anchors or drill bits and, therefore, overestimates the range of the actual insertion angles available to the surgeon. However, the acetabular rim angle as measured in this study provides an accurate and reliable measure of the variability seen across clock positions and accurately demonstrates the effect of drill depth and rim trimming on the acetabular rim angle independent of drill bit width or suture anchor design.

CONCLUSION

The acetabular rim angle varied significantly as a function of the location on the acetabular rim. Large differences in the acetabular rim angle were demonstrated at the anterosuperior quadrant, where labral tears are commonly located. The acetabular safety angle was smallest at the 3-o'clock position. Therefore, extra care must be taken when drilling or inserting anchors around the 3-o'clock position. Greater drill depths provided smaller acetabular rim angles, whereas rim trimming provided larger acetabular rim angles. These variations in safety margin should be considered when selecting the optimal insertion angle for suture anchor placement.

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