Safe Zone for Transacetabular Screw Fixation in Prosthetic Acetabular Reconstruction of High Developmental Dysplasia of the Hip

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Safe Zone for Transacetabular Screw Fixation in Prosthetic Acetabular Reconstruction of High Developmental Dysplasia of the Hip

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Background: Prosthetic reconstruction of hips with Crowe type-IV developmental dysplasia (a high complete dislocation) is technically demanding. Insufficient osseous coverage and osteopenic bone stock frequently necessitate transacetabular screw fixation to augment primary stability of the metal acetabular shell. We sought to determine whether a previously reported quadrant system for screw fixation of the acetabular cup can be applied in patients with high dislocation of the hip and to define a specialized safe zone for screw fixation in these hips, if needed.

Methods: Using volumetric computed tomographic data and image-processing software, we made three-dimensional reconstructions of the osseous and vascular structures in eighteen hips in twelve patients. We virtually reconstructed a cup in the true acetabulum and dynamically simulated transacetabular screw fixation. We mapped the hemispheric cup into several areas and, for each, measured the distance between the virtual screw and the external iliac (femoral) and obturator blood vessels. In the six patients with unilateral high dislocation of the hip and a relatively normal, contralateral hip, the six relatively normal hips served as controls.

Results: Reconstruction of the cup at the level of the true acetabulum shifted the center of rotation anteroinferiorly in the hips with a high, complete dislocation. Screws guided by the quadrant system frequently injured the obturator blood vessels in the hips with a high dislocation. In these patients, the safe zone shifted as a result of moving the prosthetic cup.

Conclusions: The quadrant system, although helpful in determining screw placement in hips with a normal center of rotation, can be misleading and of less value in guiding screw insertion to augment acetabular shells for hips with a high dislocation. We believe that a safe zone specific to hips with a high dislocation should be used to guide transacetabular screw fixation.

Level of Evidence: Diagnostic Level IV. See Instructions to Authors for a complete description of levels of evidence.

Most investigators have advocated placing the acetabular cup of a total hip arthroplasty in patients with a Crowe type-IV dislocated hip[1] at the level of the true acetabulum to optimize abductor muscle function, decrease polyethylene wear, and prevent cup loosening[2,3]. However, prosthetic reconstruction of an acetabulum in a hip with a high dislocation is technically demanding. Insufficient osseous coverage and osteopenic bone stock frequently necessitate transacetabular screw fixation to augment the stability of the metal shell.

Vascular injury is not a commonly reported complication in hip replacements[4], but it can lead to catastrophic consequences, such as hypovolemic shock, pseudoaneurysm, thrombosis, and arteriovenous fistula formation, which may necessitate emergency vascular surgery[5,6]. Vascular injury to the external iliac (femoral) and obturator vessels has been reported to range from 0.2% to 0.3%[7-9].

The relationship between the intrapelvic neurovascular bundles and the osseous acetabular structures has been well investigated[10]. Wasielewski et al.[11] developed a quadrant system

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and defined a so-called safe zone for transacetabular screw fixation. They believed that the posterosuperior and posteroinferior quadrants of the acetabulum contain good bone stock and are safe areas for the placement of transacetabular screws. However, Wasielewski et al. studied normally developed acetabuli. The acetabulum of a hip with a high dislocation is poorly developed, has a much smaller diameter than a normal hip, and usually has an inverted v-shape with a thin anterior column and relatively thicker posterior column. Three-dimensionally, the true acetabulum of a hip with a high dislocation is thus located relatively more inferiorly and anteriorly than that of a normal or less hypoplastic hip.

The purpose of this study was to determine whether the relationship between the intrapelvic blood vessels and the osseous acetabulum of a hip with a high dislocation differs from that of a normal hip. We sought to determine whether a new safe zone to guide transacetabular screw fixation was needed for such hips.

Materials and Methods

From June 2007 to August 2008, we conducted a radiographic and morphologic study of twelve patients (eleven women and one man) with a high dislocation of the hip (Crowe type IV). The mean age of the patients was forty years (range, nineteen to fifty-nine years). The mean body mass index (and standard deviation) was 22.5 ± 3.6 kg/m^2 (range, 17.9 to 30.0 kg/m^2). In the four patients with a high dislocation of both hips, the hip with the higher dislocation was selected as the research subject. In the six patients with unilateral high dislocation, the contralateral hip had mild subluxation (Crowe type I with subluxation of <50% in three patients) or was normal (three patients). The other two patients with a high dislocation had undergone previous surgery of the contralateral hip. Computed tomographic angiography was performed in all patients, and volumetric data were retrieved and input into a medical imaging program for two and three-dimensional measurement and virtual surgical simulation. Informed consent was provided by the patients before the computed tomography scan. We obtained approval from the institutional review board of the Fourth Clinical College of Peking University.

Computed Tomographic Angiography and Three-Dimensional Reconstruction

We performed computed tomographic angiography with an Aquilion sixty-four-slice spiral computed tomography scanner (Toshiba, Otawara, Japan). Using a high-pressure injector, we injected 80 mL of iohexol intravenously as a contrast medium through the cubital vein. Scanning conditions were set as follows: 120 kV, 350 mA, 1.0-mm thickness, and one-second rotation time. We set the computed tomography value threshold range from 200 to 1755 H. Scanning was started from the third lumbar level to the midpart of the femur, and the scanning duration was twenty-five to thirty-five seconds. Volumetric data were transferred to the Mimics medical imaging program (Materialise, Leuven, Belgium). Osseous structures and vessels were three-dimensionally reconstructed in two formats: surface shading display and multiplanar reconstruction.

The external iliac artery was easily distinguished by angiography and was colored red during editing. The external iliac veins contained no contrast medium but were identifiable in the transection view and confirmed by their sectional anatomic relationship with the artery. The external iliac vein was adjacent to and posterior to the external iliac artery. These veins were colored blue during editing.

The obturator artery and vein are typically branches of the internal iliac blood vessels. The obturator vein is approximately 3 mm thick and closely accompanies the obturator artery, consistently coursing backward and downward without branching[12]. We copied the artery and moved it posteriorly and inferiorly by 3 mm to simulate the obturator vein. The obturator artery and obturator vein were colored pink and cyan, respectively, during editing. Both obturator arteries in one patient were not identifiable.

We reconstructed the computed tomography volumetric data of all eighteen hips (the twelve hips with a high dislocation and the six relatively normal, contralateral hips) into three-dimensional images.

Three-Dimensional Simulated Surgery and Measurement

We located the center and the diameter of the true acetabulum in the Mimics medical imaging software (Fig. 1). We drew a hemisphere in the acetabulum to mimic a prosthetic cup and referred to it as an e-cup. The e-cup position was adjusted in orthographic coronal and sagittal images until it was positioned at the level of the true acetabulum, oriented in 45° of abduction and 15° of anteversion[11]. The inferior edge of the e-cup was placed at the level of the bottom of the teardrop, and so-called rim fit in the acetabulum was achieved. In the transverse image, the cup was confined by both the anterior and posterior columns.

In the six patients with unilateral high dislocation of the hip and a relatively normal hip on the contralateral side, we compared the distances on both sides from the center of rotation to plane A, which was defined by the pubic symphysis and both anterior superior iliac spines. The six contralateral, relatively normal hips served as controls.

We drew several 5-mm-thick radials to mimic three-dimensional screws. The radials radiated from the center of rotation, and the other end could be moved freely. After that, simulated screw fixation was performed in the twelve hips with a high dislocation and the six control hips.

We next divided the cup, as described by Wasielewski et al.[11], by extending a line from the anterior superior iliac spine through the center of the acetabulum, resulting in anterior and posterior halves. We drew a second line perpendicular to the first line at the center of the acetabulum to form superior and inferior acetabular halves.

We divided the cup into three parts: the central zone with a diameter of 1 cm, and the inner and the outer rings, which had the same widths. The inner and outer rings were divided into twelve sectors, similar to the face of a clock. We set

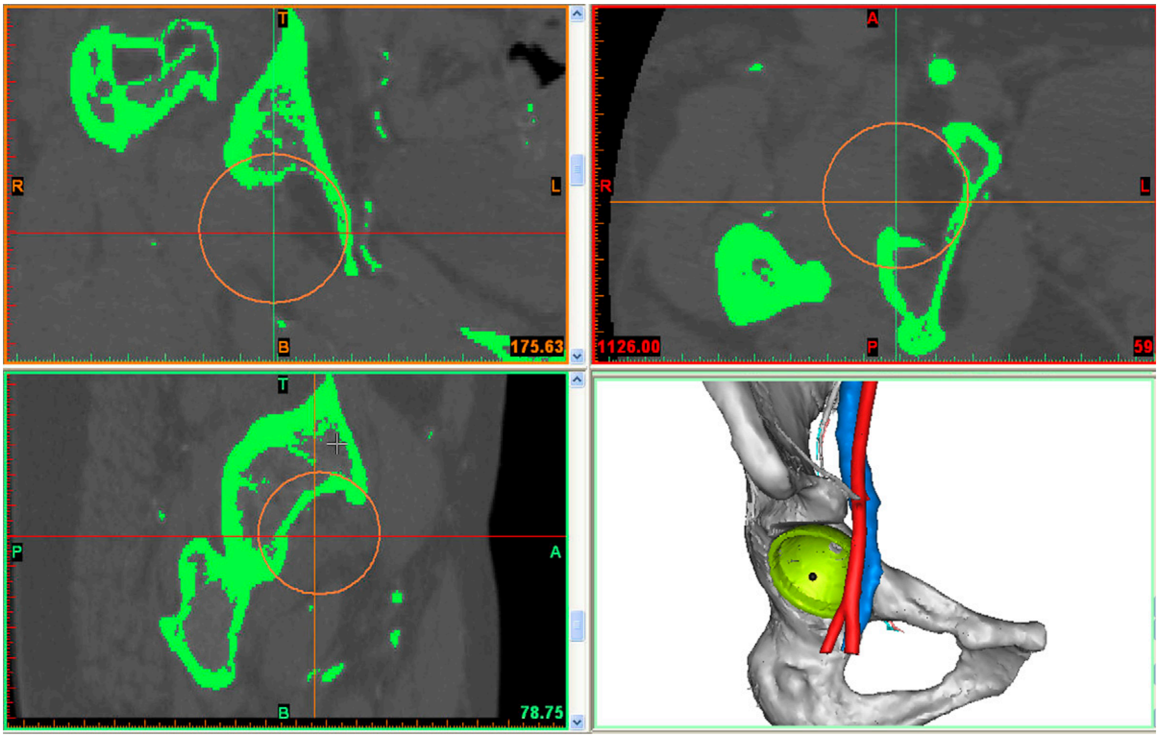

Fig. 1

The e-cup (orange circle) was placed to achieve a tight so-called rim fit with the anterior and posterior columns, and the inferior edge of the e-cup was placed at the level of the bottom of the teardrop. In this simulation, the cup diameter was 40 mm.

the anterior superior iliac spine as the point at one o'clock. Thus, we obtained twenty-four sectors and a round central zone.

During surgical simulation, we implanted one screw in every sector and two screws in the central zone. All of the radials radiated from the center of rotation. We labeled the intersecting points of the screws with different colors according to whether the screws penetrated intrapelvic blood vessels (Fig. 2).

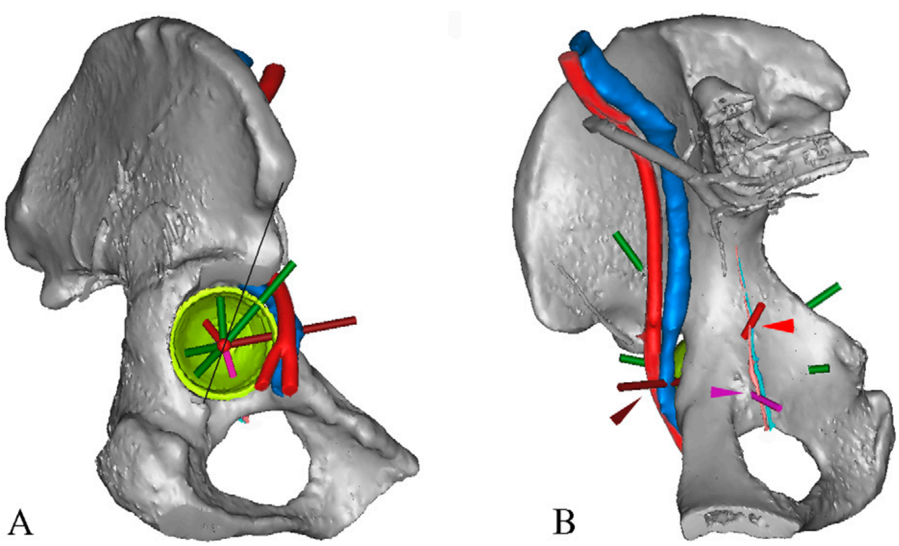

Fig. 2

The simulated surgery and potential injury of vessels. *A:* Radials radiated from the center of rotation to simulate transacetabular screw fixation. *B:* The brown screw penetrated the external iliac blood vessel (brown arrowhead). Two screws potentially injuring the obturator blood vessels (red and purple arrowheads) are demonstrated. Note that the red one was placed through the posterosuperior quadrant, which is considered a safe zone as described by Wasielewski et al.[11,19] for hips with a normal center of rotation.

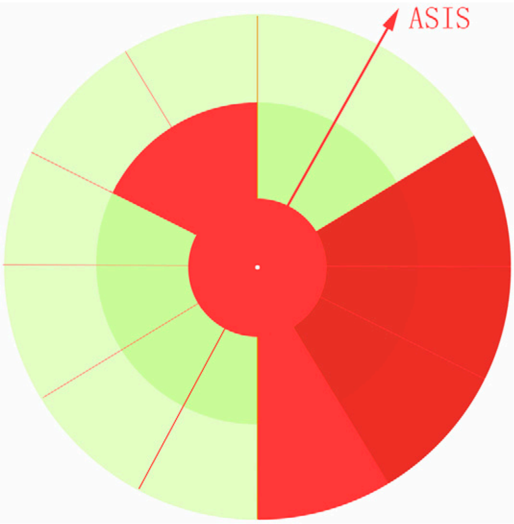

Fig. 3

The newly defined safe zone (green areas) for high dislocation of the hip. We divided a prosthetic acetabular cup into a center zone and two outer zones cut with twelve sectors, similar to the face of a clock. The unsafe areas for transacetabular screw fixation imperil the external iliac (femoral) blood vessels (dark red area) or obturator blood vessels (light red area). The location of the anterior superior iliac spine (ASIS) points to the one o'clock position.

Defining a New Safe Zone

The radials intersected the virtual cup and projected shaded areas onto the inner surface of the cup, which mimicked the screw holes. The safe zone was defined as the projected areas in which the radials did not touch any blood vessels or the radial and vessel crossing points were ≥1 cm away from the osseous surface of the inner pelvis.

Source of Funding

This study received support from the National Natural Science Foundation of China for the cost of radiographic data collection and analysis.

Results

Computed Tomographic Angiography

In all eighteen hips (twelve with a high dislocation and six relatively normal, control hips), the external iliac (femoral) arteries and internal iliac arteries were clearly identified in the angiographic reconstructed images. Both obturator arteries of one patient with a unilateral high dislocation and a normal, contralateral hip could not be seen on the angiographic images. Therefore, sixteen obturator arteries were identified in eighteen hips.

In the angiographic reconstructed images, we found that the upper portion of the obturator artery was a distance from the bone. However, below the arcuate line, which is inferior to the iliacus muscle and marks the border between the body and the wing of the ilium, the obturator artery was close to the bone surface until it entered the obturator foramen.

Simulated Surgery and Measurement

In the six patients with a unilateral high dislocation of the hip, we found that the center of rotation was closer to plane A (defined by the pubic symphysis and both anterior superior iliac spines) than it was in the control hip. The average distance from the center of rotation to plane A was 44.7 mm (range, 32.1 to 51.2 mm) in the hips with high dislocation and 49.7 mm (range, 37.0 to 57.1 mm) in the control hips. This indicates that the cup center of the hips with a high dislocation was shifted anteriorly about 5.0 mm (range, 1.1 to 8.4 mm) compared with the relatively normal, control hips. The average cup diameter was 40.3 mm (range, 38 to 44 mm) in the twelve hips with a high dislocation and 50.3 mm (range, 46 to 54 mm) in the control hips. This means the cup center of the hips with a high dislocation was shifted inferiorly in the reconstruction compared with the relatively normal, control hips.

In the six control hips, no screw in the posterosuperior and posteroinferior quadrants injured any vessel, while more than half of the screws in the anterosuperior and anteroinferior quadrants penetrated vessels. This is consistent with the safe zone described by Wasielewski et al.[11] in the relatively normal hips.

However, in the hips with a high dislocation, seventeen of the thirty-three screws driven through the posterosuperior quadrant penetrated the obturator vessels. The potential vessel injury rate was 52% (seventeen of thirty-three; 95% confidence interval, 34.5% to 68.6%). In the anterosuperior and anteroinferior quadrants, the injury rate of external iliac (femoral) vessels was 65% (forty-seven of seventy-two; 95% confidence interval, 54.3% to 76.3%) and the injury rate of the obturator vessels was 58% (nineteen of thirty-three; 95% confidence interval, 40.7% to 74.4%).

A New Safe Zone for Hips with High Developmental Dislocation

On the basis of these observations, we found three unsafe areas: ten to twelve o'clock on the inner sector (Area A) and the central zone (Area B) were potentially dangerous to the obturator vessels; the two to six o'clock sector (Area C) was potentially dangerous to the external iliac (femoral) vessels in the two to five o'clock sectors and potentially dangerous to obturator vessels in the five to six o'clock sector. Area A overlaps the posterosuperior quadrant, which is considered a safe zone, as described by Wasielewski et al., for hips with a normal center; however, we found that it was unsafe for hips with a high dislocation. The remainder of the surface of the hemisphere cup was defined as the safe zone (Fig. 3).

Discussion

Total hip replacement in patients with a high dislocation of the hip is technically demanding, especially when the surgeon tries to place a prosthetic cup at the level of the true

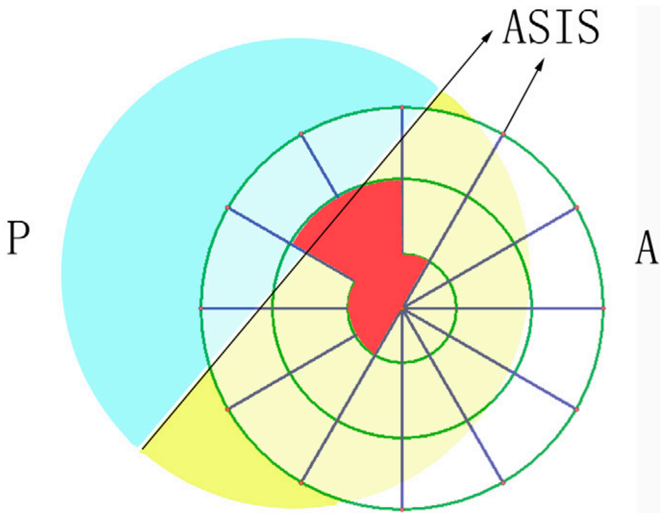

Fig. 4

Diagram demonstrating that shifting of the cup shifts the safe zone. The larger circle represents the position of a replaced cup in a relatively normal hip, and the small one represents cup position in a hip with a high dislocation. The anteroinferior migration of the cup (green) in hips with a high dislocation shifted some structures (red) that once were in the anterior (A) quadrants (yellow) into the posterior (P) quadrants, thus making what was once a safe zone no longer safe. We believe that the quadrant system as described by Wasielewski et al.[11,19] does not apply to these hips. ASIS = anterior superior iliac spine.

acetabulum to optimize abductor muscle function and decrease wear. Insufficient osseous coverage and osteopenic bone often necessitate transacetabular screw fixation to augment primary stability of the metal shell, but the screws may jeopardize intrapelvic neurovascular bundles.

The anatomic basis of transacetabular screw fixation for normal hips has been thoroughly investigated. Particular attention has been paid to the relationship between the intrapelvic neurovascular anatomy, including the external iliac (femoral) arteries and veins and the obturator arteries and veins, and the placement of transacetabular screws[13–18].

Wasielewski et al.[11,19] used cadaver and radiographic data to determine the safety of transacetabular screw fixation vis-à-vis intrapelvic neurovascular tissues. They recommended use of a quadrant system to guide screw fixation in total hip arthroplasty. However, we are aware of no similar study for high dislocation of the hip. Thus, we sought to determine whether it is safe to extrapolate the quadrant system described by Wasielewski et al. to hips with a high dislocation.

We used computed tomographic angiography and special software to determine the distance between intrapelvic blood vessels and the osseous acetabular structures of a hip with a high dislocation. These tools also allowed simulation of prosthetic cup replacement and transacetabular screw fixation so that we could define a safe zone for screw fixation. Computed tomographic angiography is a good tool, particularly for studies of abnormal anatomy. Fehring et al.[20] described the use of contrast-enhanced computed tomography scanning of the pelvis as a cost-effective method for defining intrapelvic relationships.

A major finding of our study is that the quadrant system described by Wasielewski et al. does not appear to be applicable to high dislocation of the hip. Because of the poorly developed osseous structures in these hips, even when a prosthetic cup is reconstructed in the true acetabulum, the position of the center of rotation is not normal (Fig. 4). The center of rotation was about 5 mm more anterior than in normal hips, and the average diameter of the metal shell was generally much smaller (mean, 40.3 mm), indicating that the center of rotation had migrated inferiorly.

The quadrant system described by Wasielewski et al. defines the posterosuperior quadrant as a safe zone, which we believed is applicable to normal or less dysplastic hips. However, with high dislocation of the hip, the safe zone is shifted and the posterosuperior quadrant is no longer safe.

We divided a prosthetic acetabular cup into a center zone and two outer zones cut with twelve sectors similar to the face of a clock, with the anterior superior iliac spines placed in the one o'clock location. We believe that three unsafe areas should be avoided. Area A (the ten to twelve o'clock sector of the inner portion of the outer zones) places the obturator blood vessels at risk. (Since the obturator vessels turn medially to join internal iliac blood vessels in the outer portion of this sector, we believe that region is safe for screw fixation.) We believe that Area B (the central zone) of the prosthetic acetabular cup should not be used for screw fixation. We found that most of the obturator blood vessels were closely adjacent to the inner side of the bone in the central zone. Fortunately, this area is seldom used for screw augmentation because it does not provide enough bone stock for good screw purchase. Lastly, we believe that Area C (the two to six o'clock sector) theoretically places the external iliac (femoral) vessels in the two to five o'clock sector and the obturator vessels in the five to six o'clock sector at risk. This area is adjacent to the anterior column, which typically does not provide enough bone stock for good screw purchase either.

Our study had several limitations. The sample size was not very large; however, high dislocation is not a common condition. Further, the femoral and obturator nerves were not visible with angiography. However, these nerves accompany the homonymous blood vessels in a neurovascular bundle. Therefore, we believe that a safe zone defined by a vascular structure may be used also to avoid nerve injury in patients who have a hip with a high dislocation.

Prosthetic reconstruction of hips with a high dislocation is technically demanding. We believe that the information regarding the safe zone for such hips may be useful in avoiding injury to neurovascular structures. Further, the surgeon should consider using a multihole cup rather than a cluster-hole cup in these hips in order to provide more options for screw fixation. ■

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