CLINICAL ARTICLE

An Alternative Intraoperative Radiographic Method for Optimizing Cup Inclination during Total Hip Arthroplasty

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Objective: During total hip arthroplasty (THA), the location of the acetabular prosthesis is very important for guaranteeing successful surgery. However, this remains a challenge for many surgeons. This study aimed to investigate the feasibility of using the intraoperative fluoroscopic iliopubic tangential angle (IPTA) to determine the valgus angles of acetabular prostheses.

Methods: In the first stage, the IPTA and valgus angles of native acetabula were defined and measured in 102 THAs obtained from the picture archiving and communication systems of our hospital. Obturator foramen morphology was also measured and divided into groups according to the axial length ratio. Correlations between obturator foramen morphology and IPTA and valgus angles of native acetabula were then determined. In the second stage, angular differences (angle θ) between the IPTA and valgus angles of native acetabula were measured during unilateral THA in 136 patients to determine whether this is a stable value that could be used as a reference for placement of acetabular prostheses. Postoperative data such as Harris Hip Score (HHS) scores and complications were collected and evaluated.

Results: The average IPTA at the apex of the true acetabulum was $58.8^\circ \pm 4.1^\circ$. The average valgus angle of native acetabula was $43.1^\circ \pm 3.9^\circ$ and angle θ was $15.7^\circ \pm 1.3^\circ$. Obturator foramen morphology was divided into five groups according to the axial length ratio. IPTA was closely related to obturator foramen morphology (Pearson $r = 0.489$, $P \approx 0.000$). Angle θ was stable and independent of obturator foramen morphology. When the IPTA and angle θ were used as references for placing acetabular prostheses in 136 THAs, the average postoperative valgus angles of acetabular prostheses was $45.13^\circ \pm 4.07^\circ$ and the good-to-excellent rate was 97.05%. There were no short-term complications such as fracture, dislocation or infection. The average HHS score 6 months after surgery was 37.2 higher than the preoperative score, this difference being significant ($P < 0.01$). Neither infection nor dislocation was found 6 months after surgery.

Conclusions: The IPTA (at the apex of the true acetabulum) and angle θ (obtained by intraoperative fluoroscopy) are consistent in determining the postoperative valgus angle of acetabular prosthesis during THA. Thus, IPTA and angle θ are of value in guiding placement of acetabular prostheses; in particular, this method can facilitate the learning of young surgeons.

Key words: Cup inclination; Iliopubic tangential angle; Radiographic method; Total hip arthroplasty

Introduction

Total hip arthroplasty (THA) for femoral head necrosis, hip osteoarthritis and developmental dysplasia of the hip (DDH) has satisfactory outcomes^{1,2}.

A successful THA depends on accurate placement of the prosthesis; however, it is difficult to achieve perfect alignment of the acetabular component, which has a direct effect on the outcome of THA³. The location of the acetabular

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prosthesis is very important in guaranteeing a successful THA⁴, malpositioning including abnormal acetabular angle, abnormal anteversion, poor acetabular coverage and acetabular center migration.

The valgus angle of an acetabular prosthesis can more easily be measured than anteversion of the acetabular component. In 1978, Lewinnek *et al.* defined the concept of the "safe zone," in which they determined the safe range of the valgus angle was $40^{\circ} \pm 10^{\circ}$; this value has been widely applied in clinical practice for many years⁵. However, Barrack *et al.* measured the prosthetic angles of 1549 patients who underwent THA and found that the ideal acetabular valgus angle was 30° – 55° and the rate of abnormal valgus angle of the acetabular prosthesis approximately 7% according to this standard⁶. Moreover, malpositioning of the acetabular valgus angle can result in serious adverse effects. Short-term complications associated with excessive valgus angle include leg length discrepancy, prosthesis impingement syndrome, breakage of ceramic prostheses, whereas long-term complications include prosthetic dislocation, wear, increased release of metal ions, decreased survival of the prosthesis and increased need for revision surgery^{7–9}.

De Haan *et al.* showed a direct relationship between an increase in metal ions in the peripheral blood and an excessively large acetabular valgus angle⁸, a finding later confirmed by Desy *et al.*⁷ Georgiades *et al.* found that prostheses with valgus angle greater than 45° had significantly more wear¹⁰. In addition, recent studies have found that an abnormal acetabular valgus angle can induce prosthetic impingement syndrome and leg length discrepancy^{11,12}.

The key to avoiding abnormal valgus angles of acetabular prostheses is their accurate intraoperative placement.

Conventional freehand insertion is still the most widely used technique for cup implantation in THAs. Currently, techniques for controlling the valgus angle of acetabular prostheses during surgery include preoperative planning, intraoperative localization of anatomical landmarks (including the morphology of the acetabulum, oval fossa and transverse ligament), assistance from localizing devices, intraoperative image monitoring, navigation and comprehensive assessment^{13–16}. It is worth mentioning that a new method called 3-D-planning-assisted reportedly increases the accuracy of restoration of anteversion and reduces the percentage of outliers without increasing the operative time. However, the authors stressed they did not demonstrate the same advantage for abduction¹⁷.

Because the patient's intraoperative position may induce varying degrees of tilt and rotation, the surgeon, especially if relatively inexperienced, may not accurately grasp the impact of the patient's position as it relates to the required angles during surgery. Moreover, the transverse acetabular ligament can be used to achieve the appropriate degree of anteversion when introducing the acetabular component during THA¹⁸. In addition, although a surgical navigation system provides greater accuracy and advanced navigation techniques, such systems cannot be used

extensively because they are relatively expensive and prolong the duration of surgery. In contrast, intraoperative fluoroscopy is simple and less time-consuming and is widely used in clinical practice¹⁹. Ezzet and McCauley found that intraoperative anteroposterior (AP) pelvic radiography is very useful for managing THAs¹⁹. In a series of over 200 consecutive primary THAs, they found single intraoperative AP pelvis radiography to be a reliable, quick, and inexpensive means of determining acetabular abduction, acetabular medialization, leg length and femoral alignment. However, AP pelvic radiography is less convenient to perform in operating rooms than local fluoroscopic imaging, local fluoroscopic being easy and convenient. However, the latter does not supply information on the whole pelvis, which may easily be rotated, thereby resulting in an abnormal acetabular angle.

Although intraoperative radiographs for guiding component orientation have been evaluated, local fluoroscopic imaging of the iliopubic tangential angle (IPTA) has not been formally evaluated as a tool for use during THA. We here propose an alternative means of determining the valgus angle of the acetabular prosthesis that uses the IPTA, as measured using intraoperative local fluoroscopy. We have observed the iliopubic line is an arcuate line and measured the angle between the IPTA (at the apex of the true acetabulum) and a horizontal line. The purpose of the present study was twofold. First, we aimed to measure the IPTA and this related angle to determine whether the IPTA and related angle is stable in different individual THAs and to ascertain a reference value. Second, we aimed to determine whether such an angle obtained by local fluoroscopic imaging reliably and reproducibly guides the right acetabular position. We hypothesized that the use of the IPTA and related angle intraoperatively would increase the accuracy of cup orientation over that achieved by conventional freehand implantation.

Subjects and Methods

Stage 1

Subjects

This stage of the study was approved by our Institutional Review Board. Written informed consent for this study was waived because of the retrospective nature of our clinically acquired data. At the time of the examination, however, all patients had given consent to use their clinical and imaging data for research purposes.

Pelvic radiographic data from 102 eligible subjects (51 men and 51 women; average age, 56.3 years; range, 20–84 years; average body mass index, $23.44 \pm 3.08 \text{ kg/m}^2$) were obtained from the picture archiving and communication systems (PACS) system at our hospital for the year 2013. Inclusion criteria were as follows: (i) >18 years of age; (ii) no history of pelvic deformity, fracture or tumor; and (iii) no history of pelvic or femoral surgery. Anteroposterior pelvic X-ray films containing both hip joints were obtained for each patient.

Fig. 1 Anteroposterior weight bearing pelvic radiograph of a male patient. The acetabular valgus angle (AA), α , is the angle between the solid purple line connecting the lateral margin of the acetabulum and inferior margin of the teardrop and the dashed purple line connecting the two teardrops. The IPTA, β , is the angle between the solid red line and dashed red line connecting the two teardrops. The acute angle, θ , is between the dashed purple line and dashed red line (i.e., $\theta = \text{IPTA} - \text{AA}$, where AA = acetabular valgus angle). The two dashed blue lines are the maximum long and short diameters.

Methods

Using a Phillips–Stentor PACS system (Brisbane, CA, USA), the following variables were measured on anteroposterior pelvic X-ray films, as shown in Fig. 1: (i) valgus angle of native acetabula, α , (defined as the angle between the line connecting the lateral margin of the acetabulum and inferior margin of the teardrop and the line connecting the two teardrops); (ii) IPTA, β , at the apex of the true acetabulum (defined as the angle between the iliopectoral tangential line at the apex of the acetabulum and the line connecting the two teardrops); (iii) an acute angle, θ , between the line connecting the lateral margin of the acetabulum and the teardrop and the IPTA (i.e., $\theta = \text{IPTA} - \alpha$); and (iv) the ratio (a/b) of the maximum inferomedial-superolateral diameter of the obturator foramen (Fig. 1).

All data were measured and collected by two experienced surgeons using the same measurement standards, each surgeon measuring the variables of 51 of the 102 cases.

Stage 2

Subjects

This stage of the study was approved by our Institutional Review Board. Written informed consent for this study was obtained from all patients prior to their participation.

The second stage, the clinical trial portion of this study, involved 136 patients (38 men and 98 women; average age, 63.07 years; range, 41–79 years) who underwent THA between May 2013 and March 2014 and had complete data sets. Inclusion criteria were: (i) >18 years of age; (ii) no history of pelvic deformity, fracture or tumor; (iii) no history of pelvic or femoral surgery; and (iv) a follow-up duration of more than 6 months.

Of the 136 patients, 80 (59%) had diagnoses of femoral head necrosis (30 with Ficat stage III and 50 with Ficat stage IV), 40 osteoarthritis and 16 DDH. The average body mass index was $25.67 \pm 2.98 \text{ kg/m}^2$ and preoperative Harris Hip Score (HHS) score 53.0 ± 7.5 .

Methods

The average preoperative HHS was 53 (range, 26–76 points) and the average duration of follow-up 8.3 months. All patients underwent THA by an experienced orthopedic surgeon via the Hardinge approach. Fluoroscopy was performed intraoperatively before placing the prosthesis during surgery and the angle θ measured on the fluoroscopic image. With the value of θ falling into the interval ascertained in Stage 1 from radiographs, the ideal acetabular valgus angle was calculated (the two doctors mentioned above participated in these calculations).

The acetabular prosthesis was then placed according to the reference angle θ value obtained in Stage 1 and relevant intraoperative data recorded. Five days after surgery, pelvic X-ray images were obtained and the postoperative valgus angle calculated using the PACS tools. Pelvic radiographs and postoperative complications were evaluated 3, 6, 9, and 12 months after surgery.

Statistical Analysis

All measurements were performed by two independent observers. Measurements were repeated on a random set of 20 radiographs to determine intra-observer reliability. Inter- and intra-observer reliability were evaluated using a one-way random intra-class correlation coefficient. The correlations between values (i.e. the morphology of the obturator foramen, and the angles α , β and θ) were evaluated by Pearson correlation analysis, whereas the significance of the differences was assessed by the least significant difference (LSD). A *P* value of 5% was considered statistically significant. All statistical calculations were performed using SPSS software, Version 13.0.

Results

Stage 1: Iliopubic Tangential Angle and Its Relationship to the Valgus Angle of Native Acetabula

The average valgus angle of native acetabula, that is, angle α , was $43.1^\circ \pm 3.9^\circ$; the average IPTA, that is, angle β , $58.8^\circ \pm 4.1^\circ$; and the average angle θ $15.7^\circ \pm 1.3^\circ$. Because individual pelvic obturator foramen morphology differed according to the rotational angles, we divided foramen morphologies into five groups according to the value of a/b

Fig. 2 Distribution of iliopubic angles by different shaped obturator foramen groups. Obturator foramens shapes were divided into five groups according to the value of a/b (0.5, 1.0, 1.5, 2.0, 2.5). The value a is the maximum long diameter of the obturator foramen whereas b is the maximum short diameter.

(0.5, 1.0, 1.5, 2 and 2.5) (Fig. 2) Pearson correlation analysis showed a close correlation between the morphology of the obturator foramen and the IPTA (Pearson $r = 0.489$, $P \approx 0.000$), namely, a small a/b value meant a flat obturator foramen and a large IPTA. Various groups were compared using LSD and the significance of the differences in a/b values (i.e., the morphology of the obturator foramen) between the various groups determined.

There was a significant correlation between the valgus angle of native acetabula and the morphology of the obturator foramen (Pearson $r = 0.503$, $P = 0.00$). However, there was no significant correlation between the morphology of the obturator foramen and the angle θ (Pearson $r = 0.012$, $P = 0.901$).

LSD analysis showed significant differences between the various foramen morphology groups (i.e., 0.5, 1.0, 1.5, 2 and 2.5). The above results proved that the IPTA and valgus angle of native acetabula are separately closely related to the morphology of the obturator foramen, whereas the angle θ is a stable value that has no correlation with the morphology of the obturator foramen. We can therefore use the IPTA and angle θ to determine the postoperative valgus angle of acetabular prosthesis. We also determined the reference range for angle θ . Based on these results, we conducted the clinical trial (Stage 2).

Stage 2: The Clinical Trial

We replicated the preoperative angle θ ($\theta = 15.7^\circ \pm 1.3^\circ$) on X-ray images during intraoperative fluoroscopy, and obtained an ideal acetabular valgus angle by intraoperative fluoroscopy based on the preoperative valgus angle of native acetabula in Stage 2.

Fig. 3 Distribution of the postoperative valgus angles of acetabular prostheses.

The average postoperative valgus angle of acetabular prosthesis was $45.13^\circ \pm 4.07^\circ$ (95% CI, 37.1° – 58.6°). The angles from 132 cases were distributed within the range of the Barrack standard (30° – 55°), whereas four cases had angles $>55^\circ$. The good-to-excellent rate was 97.05% (Fig. 3). The average postoperative IPTA was $58.1^\circ \pm 4.6^\circ$ and postoperative angle θ $14.71^\circ \pm 1.69^\circ$. The difference in IPTA between male and female patients was 2.0° , which is not significant ($P > 0.05$).

There were no short-term complications such as fracture, dislocation or infection. The average HHS score 6 months after surgery was 90.2 (range, 68–100), which is 37.2 higher than the preoperative score; this difference is significant ($P < 0.01$). No infection or dislocation was found 6 months after surgery. Two patients had deep vein thromboses in their lower extremities, which were relieved with medication.

Discussion

Need for Accurate Placement of Acetabular Valgus Angle during THA

Malpositioning of the acetabular valgus angle can result in serious adverse effects. Lewinnek *et al.* initially found that a valgus angle exceeding the “safe zone” was frequently associated with postoperative dislocation⁵. Georgiades *et al.* found that prostheses had significantly more wear when the valgus angle was greater than 45° ¹⁰. De Haan *et al.* showed that an increase in metal ions in the peripheral blood is directly related to an excessively large acetabular valgus angle⁸, a finding later confirmed by Desy *et al.*⁷ In addition, recent studies have found that an abnormal acetabular valgus angle can induce prosthetic impingement syndrome and leg length discrepancy^{11,12}. In the present study, we developed intraoperative fluoroscopic IPTA as a reliable tool for assisting surgeons to increase the accuracy of acetabular prosthetic placement.

Three Coordinate Systems of the Acetabular Angle during THA: Anatomic, Surgical, and Radiologic Coordinate Systems

The spatial relationship between the acetabular prosthesis and the pelvis can be described using location and angle. The location refers to the relationship between the centers of the acetabular prosthesis and of the bony acetabulum, namely superior and inferior, anterior and posterior, and medial and lateral. The angle refers to the direction of the opening of the acetabular prosthesis, which can be described by the inclination (chamber angle, abduction angle) and anteversion. Murray summarized the surgical, radiological and anatomical definition methods²⁰.

Defining the acetabular angle can facilitate accurate acetabular prosthetic placement during surgery. In fact, the surgeon identifies the surgical valgus angle and anteversion with the assistance of various devices during surgery. However, we used intraoperative fluoroscopy to determine these angles, which may differ from the actual angles. According to a study by Murray²⁰, when the valgus angle is 45° and anteversion 0°, the radiological inclination is 45°; whereas when acetabular anteversion is 30°, the radiological valgus angle is significantly more than 45°. Therefore, the radiological valgus angle should be adjusted so that it is equal to or less than 45° to reduce the wear at the interface, and the surgical valgus angle should be less than 45° when placing the acetabular prosthesis. Moreover, the surgical valgus angle should be small when anteversion is large.

Shortcomings of Commonly Used Methods to Determine the Acetabular Valgus Angle: The Influence of Position on Surgery

Currently, methods for controlling the valgus angle of the acetabular prosthesis during surgery include preoperative planning, intraoperative locators, assistance from surgical devices, intraoperative image monitoring, navigation and comprehensive assessment^{13–15}. Although current surgical

navigation systems can improve the accuracy of prosthetic placement during THA, these systems are relatively expensive and cannot be applied in all cases^{15,21}. An intraoperative locator is still primarily used for placement of the acetabular prosthesis during THA. However, patients undergoing surgery via a lateral approach are commonly placed in a lateral recumbent position and pelvic fixation becomes uncertain when the location of the lower extremity is changed during surgery. Intraoperative procedures such as hip dislocation can easily induce rotation of the pelvis, rendering it difficult for the surgeon to determine the position of the pelvis, which ultimately affects the placement of the prosthesis (Fig. 4). All these factors make it hard for young physicians to learn and master the skill of accurate placement of an acetabular prosthesis.

Asayama *et al.* designed a device for real-time measuring of the activity of the pelvis during surgery and found varying degrees of internal rotation of the pelvis (5.0°–31.0°) in the patients studied^{13,22,23}. Therefore, even experienced surgeons cannot accurately evaluate changes in angle caused by rotation of the pelvis when relying only on a simple locator²⁴. Moreover, new intraoperative anatomical markers are continually being discovered and applied in clinical practice. Archbold *et al.* suggested guiding placement of an acetabular prosthesis using the transverse ligament of the acetabulum; this method has improved the accuracy of acetabular placement. However, it primarily improves anteversion, minimally increasing the accuracy of the abduction angle²⁵.

We found that intraoperative fluoroscopic determination of prosthesis location is a simple and less time-consuming method for the placement of the acetabular prosthesis²⁶. However, factors such as intraoperative rotation of the pelvis make it difficult for surgeons, particularly young surgeons, to determine the condition of the whole pelvis and the acetabular valgus angle (Fig. 5).

In the present study, we used a combination of the IPTA at the apex of the true acetabulum and the included angle θ as reference indicators for acetabular prosthetic

Fig. 4 Photographs showing the influence of different patient positions on acetabular implantation intraoperatively. (A) Intraoperative localization with a position guide apparatus. (B, C) Different patient positions lead to abnormal pelvic tilts.

Fig. 5 The illusions in local fluoroscopic images produced by intraoperative rotation of the same acetabular cup position. All three images were of the same acetabular cup position. (A) Local fluoroscopic image when rotated anticlockwise; (B) local fluoroscopic images without rotation; and (C) local fluoroscopic images when rotated clockwise.

placement during intraoperative fluoroscopy. We also showed that the acute angle θ ($\theta = 15.7^\circ \pm 1.3^\circ$) is stable. Thus, we referred to the IPTA and the angle θ during surgery in Stage 2 to determine the valgus angle of the acetabular prosthesis.

Based on this method, the average valgus angle of the acetabular prosthesis after THA was $45.13^\circ \pm 4.07^\circ$ (95% CI, 37.1° – 58.6°) in the present study, 97.05% of angles being in the safe zone. Our results confirm that this method is a reliable tool for determining the valgus of acetabular prostheses. In addition, this method can be widely applied in clinical practice because it utilizes intraoperative fluoroscopy, which is simple, convenient and readily available.

Our study has several limitations, including the small number of cases and the fact that it was a non-controlled study. Future prospective controlled studies with larger cohorts of patients are needed to confirm our results.

In addition, the iliopubic line is an irregular parabolic curve and the iliopubic tangential line requires accurate localization of the true floor of the acetabulum. Particularly in patients with DDH, the apex of the acetabulum is difficult to identify because of the abnormal morphology of the acetabulum caused by pathological changes. In the present study, we identified the location of the true acetabulum preoperatively in patients with DDH and reconstructed the true acetabulum during surgery according to our preoperative plans. Therefore, the IPTA and angle θ were measured at the fixed position of the true acetabulum. Of course, errors may

occur when the identification of the apex of the true acetabulum is not completely accurate. Also, the preoperative and postoperative valgus angles were obtained in the supine position whereas the intraoperative valgus angle was obtained in the lateral recumbent position. Thus, there may be differences in the angles between these two positions. However, the different morphologies of the obturator foramen had little impact on the acetabular valgus angle and induced relatively insignificant errors.

Finally, the surgery was performed by the same surgeon using the same surgical approach. Thus, it was impossible to judge the impact of the surgical approach on the intraoperative angles.

Conclusion

The IPTA (at the apex of the true acetabulum) and the angle θ (obtained by intraoperative fluoroscopy) consistently determine the postoperative valgus angle of acetabular prostheses during THA. Thus, IPTA and angle θ are of value in guiding placement of acetabular prostheses; in particular, they are useful in facilitating young surgeons learning.

Author Contributions

Our thanks to HLD and YYQ for participating in the design of the study and performing the statistical analysis. SJS and CJ helped to draft the manuscript. WJG participated in design and coordination and helped to draft the manuscript.

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