Original article

Evaluation of Bony Impingement in Regard to Internal Rotation Limit after Total Hip Arthroplasty Using Rotation Matrix

Koji Suzuki¹, Masaaki Matsubara², Akimasa Ishida³ and Shoji Imai³

¹Department of Orthopaedic Surgery, JA Toride Medical Center, Japan

²Department of Orthopaedic Surgery, Nissan Tamagawa Hospital, Japan

³Department of Biomedical Information, Institute of Biomaterials and Bioengineering, Tokyo Medical and Dental University, Japan

Abstract

Objectives: Bony impingement of the proximal femur on the pelvis is an important factor for dislocation after total hip arthroplasty (THA). We evaluated bony impingement after THA using the rotation matrix derived from postoperative computed tomography (CT) images.

Patients and Methods: One hundred and seven hip joints were subjected to primary THA via a posterolateral approach. We used the rotation matrix derived from CT images to calculate internal rotation (IR) limit prior to bony impingement, and compared this limit with the intraoperative limit.

Results: The average calculated IR limit was 63 degrees (range: 30 to 85 degrees). The average intraoperative IR limit was 49 degrees (range: 20 to 70 degrees). The correlation between the intraoperative IR limit (Y) and the calculated IR limit (X) was expressed as $Y=8.9+0.66X$ ($R=0.73$; $p < 0.0001$).

Conclusions: We could show a patient's safe range of motion prior to bony impingement, and this will be a good indicator for dislocation not occurring during postoperative rehabilitation.

Key words: total hip arthroplasty, dislocation, rotation matrix, computed tomography, bony impingement

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Introduction

Dislocation is one of the most serious complications after total hip arthroplasty (THA), and the postoperative dislocation rate of THA has been reported to be between 0.6% and 7%^{1–5}. Malpositioning of the components, prosthetic impingements, bony impingements, decreases in muscle

tonus and multiple surgeries are some of the factors contributing to dislocation after THA^{1–4,6}. There are reports describing dislocation in relation to surgical approach^{7,8}, cup positioning² and prosthetic impingement⁶. Bony impingement of the proximal femur on the pelvis is one such factor⁹. Bony impingement is an important factor for dislocation if the position of the implant is appropriate⁹.

A three-dimensional transformation matrix is useful for describing three-dimensional rotational motion of the body^{7,10,11}. We used a rotation matrix derived from CT images to evaluate bony impingement after THA in relation to internal rotation limit.

Patients and Methods

Patients

One hundred and seven hip joints in 102 patients (16 males and 86 females) were subjected to primary THA. The diagnoses necessitating THA were osteoarthritis in 92 cases, osteonecrosis in 13 cases and rheumatoid arthritis in 2 cases. The patients' average age was 62 years (range: 40 to 84 years), their average weight was 53.4 kg (range: 34 to 75 kg) and their average height was 152 cm (range: 133 to 180 cm). All the operations were carried out consecutively between May 1998 and June 2000 by the same surgeon, who used a posterolateral approach and with a true lateral position. The implant used was the Perfix stem (Kyocera Corporation, Kyoto, Japan) with an alumina head 28 mm in diameter, a neck 13 mm in diameter at the base and a head/neck ratio of 2.15, and the acetabular side had an ABS (alumina bearing surface) cup. We selected this series because we could detect the contour of the ceramic head and clearly detect the center of the femoral head (Figure 3b). A flat acetabular liner with no marginal lips was used for every pa-

Correspondence to: Koji Suzuki, Department of Orthopaedic Surgery, JA Toride Medical Center, 2-1-1 Hongo, Toride, Ibaraki 302-0022, Japan
E-mail: kojisuzuki325282@aol.com

Figure 1 Definition of the spatial coordinates. Taking the center of the femoral head as the origin, the cephalocaudal direction was defined as the X axis, the dorsoventral direction was defined as the Y axis and the left-right direction was defined as the Z axis.

tient. The oscillation angle of the implant was 120 degrees. The short external rotators were detached with the posterior capsule, reattached after placement of the implant and finally restored using complete posterior capsular and muscular repair¹²⁾. Two days after surgery, patients were permitted to bear weight if it was tolerable, and they were encouraged to carry out weight-bearing activities as soon as possible. In this series, postoperative dislocation did not occur.

Procedures

CT scans were performed within two weeks after the operation. CT scans (obtained using a GE HiLight Scanner (GE Medical Systems, Milwaukee, WI, USA) were employed for this study. The area of the hip joint from the anterior superior iliac spine to below the lesser trochanter and several 3-mm slices through the distal femoral condyles were scanned to obtain 3-mm-thick transverse slices spaced 3 mm apart.

The reference coordinate system attached to the pelvis and the moving coordinate system attached to the femur were assumed to be in the same position and attitude in the CT images.

Taking the center of the femoral head as the origin, the cephalocaudal direction as the X axis, the dorsoventral di-

rection as the Y axis and the left-right direction as the Z axis (Figure 1), the spatial coordinates of the position of the proximal femur in the moving coordinate system (x_0, y_0, z_0) were determined from the CT images, and x_0, y_0 , and z_0 were determined for the most anterior point of the greater trochanter in the CT images. We used the coordinate transformation equation given below to calculate the spatial coordinates of the position of the proximal femur after it was moved into a flexed position at 90 degrees and then moved further to the IR limit until the proximal femur reached the acetabular rim or iliac wall.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos(\text{flex}), -\sin(\text{flex}) \cos \text{IR}, \sin(\text{flex}) \sin \text{IR} \\ \sin(\text{flex}), \cos(\text{flex}) \cos \text{IR}, -\cos(\text{flex}) \sin \text{IR} \\ 0, \sin \text{IR}, \cos \text{IR} \end{pmatrix} \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix}$$

where the adduction-abduction angle was assumed to be zero for comparison of intraoperative measurement. The flexion angle was assumed to be 90 degrees in this series (Figure 2b). We used the MATLAB® software (The MathWorks, Inc., Natick, MA, USA) for matrix computation for these calculations and determining the mesh graphics of the iliac wall and proximal femur (Figure 2a). MATLAB® is a high-level technical computing language and interactive

Figure 2 a (Left). Mesh graphics of the iliac wall and proximal femur determined using MATLAB®. The white arrow shows the IR limit where the proximal femur reached the acetabular rim (bony impingement point). b (Right). Schema of the IR motion at 90 degrees hip flexion.

environment for algorithm development, data visualization, data analysis and numerical computation.

Measurement of the IR limit prior to bony impingement in regard to posterior stability

We represented the proximal femur as the closest point to the pelvis during IR under conditions of 90 degree hip flexion and neutral adduction/abduction (Figure 2). The maximum IR limit prior to bony impingement was calculated using the coordinate transformation equation given above.

Measurement of the intraoperative rotation limit

After placement of the implant, the IR limit prior to impingement was measured with a goniometer, before the short external rotators and iliotibial ligament were repaired, under conditions of 90 degrees hip flexion and neutral adduction/abduction, which are positions thought to cause posterior dislocation. We applied a rotational force until subluxation occurred due to bony impingement between the proximal femur and the acetabular rim or the intercalated soft tissues between the proximal femur and the iliac wall. The rotation limit was defined as the angle between the axis of the tibia and the horizontal plane.

Implant placement

For implant placement, we measured the angles of version of the femoral component, cup abduction and cup anteversion. We measured cup abduction based on radiographic definition, and we measured cup anteversion based on anatomical definition¹³. The version of the femoral component was measured using the posterior femoral condylar line on the CT images for reference, cup anteversion was measured using a vertical line to the posterior edge of the ischium for reference and cup abduction was measured using a horizontal line drawn through the bottom edge of the teardrops for reference¹³ (Figure 3).

Data analysis

Simple regression analysis was used to determine correlations between parameters. We determined regression coefficients and their 95% confidence intervals, and correlations at $p < 0.01$ were considered significant.

Results

The average calculated IR limit was 63 degrees (range: 30 to 85 degrees), and the average intraoperative IR limit

Figure 3 Definition of the position of the implant. a: The version of the femoral component. b: The cup anteversion angle. c: The cup abduction angle.

was 49 degrees (range: 20 to 70 degrees). The correlation between the IR limit under conditions of intraoperative hip flexion at 90 degrees and neutral adduction/abduction (Y) and the calculated IR limit (X) was expressed as $Y=8.9+0.66X$ ($R=0.73$; $p < 0.0001$; Figure 4).

The average version of the femoral component was 40 degrees (range: 20 to 65 degrees), the average cup anteversion was 18 degrees (range: 10 to 30 degrees) and the average cup abduction was 45 degrees (range: 34 to 48 degrees).

Discussion

We used the rotation matrix^{7,10,11)} determined from CT images to develop a new method of evaluating bony impingement after THA. A three-dimensional transformation matrix is useful for describing three-dimensional rotational motion of the body^{7,10,11)}. Therefore, we used this method because the hip joint moves in three dimensions: flexion-extension, abduction-adduction and internal rotation-external rotation. The IR limit with the hip in flexion at 90 degrees calculated by this method averaged 63 degrees, and the average intraoperative IR limit was 49 degrees. There was a significant correlation between the calculated and intraop-

erative IR limits ($R=0.73$, $p<0.0001$). If implant positioning is appropriate and bony impingement is the cause of dislocation, we can use the rotation matrix derived from CT images to quantify the rotation limit prior to bony impingement.

We can show a patient's safe range of motion prior to bony impingement, and this will be a good indicator for dislocation not occurring during postoperative rehabilitation. In this study, we obtained images of the THA in the most risky position for posterior dislocation, calculated the IR limit with the hip positioned at 90 degree hip flexion in neutral adduction/abduction and then compared it with the IR limit measured intraoperatively. We can calculate the rotation limit prior to bony impingement in any position with this method.

The calculated IR limits tended to be higher than the IR limits determined intraoperatively. We consider possible reasons for this are that the soft tissues intercalated between bones were ignored when calculating with this method and/or that the lateral positioner prevented hip flexion from reaching 90 degrees due to interference and muscle contraction. Another reason was that we intraoperatively measured the IR limit before we repaired the short external rotator muscles and iliotibial ligament.

The intra-operative IR limit (Y)

Figure 4 There was a significant correlation between the IR limit under conditions of intraoperative hip flexion at 90 degrees and neutral adduction/abduction (Y) and the calculated IR limit (X).

With respect to implant positioning, the mean version of the femoral component was 40 degrees, and the average cup abduction and anteversion were 45 and 18 degrees, respectively. All the THAs in this study were in what Lewinnek *et al.*²⁾ called the “safe zone”, and there was no so-called “mal-positioning”. If the position of the implant is appropriate, the morphology of the bone around the acetabulum or proximal femur is an important factor for bony impingement⁹⁾.

Although exposure to radiation and the cost of examination are demerits of CT, the exact angles of cup anteversion and version of the femoral component cannot be reliably measured on conventional radiographs. However, CT provides accurate information on cup and neck anteversion and bone morphology around the hip joint¹³⁾.

It is difficult to pinpoint exactly the centers of femoral heads made of metals such as Co-Cr because halations occur on CT images. However, in our study, we used ceramic heads and could locate their centers accurately, as there was no halation.

Since the main purpose of this study was to develop a method for evaluating bony impingement, there is plenty of room for further refinement of this method. For example, the processes we carried out manually, such as detection of bony contours, should be done automatically. We have to be sure that the intraoperative IR limit and the calculated IR limit are measurements based on different positions. We measured the intraoperative IR limit with a true lateral position, and the calculated IR limit was based on CT images taken with a supine position. In a future study, we will take this research further and attempt to simulate the rotation limit prior to bony impingement preoperatively.

Conclusion

We have developed a method using a rotation matrix derived from CT images for evaluating bony impingement after THA.

We could show a patient’s safe range of motion prior to bony impingement, and this will be a good indicator for postoperative rehabilitation without the occurrence of dislocation.

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