What´s the tolerated width of periacetabular osteophytes to avoid impingement in cementless THA?: A 3-dimensional simulation study

Abstract

Backgrounds

Impingement is a risk factor for instability and prosthetic failure following total hip arthroplasty (THA). If the periacetabular osteophytes are not removed at surgery, impingement could occur between the osteophytes and the femoral stem following THA. However, excessive removal of the osteophytes could lead to bleeding from the bone. The aim of our study therefore was to locate the site of the impingement and to determine the width of tolerable osteophytes, which does not induce impingement during activities of daily living (ADL), using a 3-dimensional simulation.

Methods

On 35 hip models, virtual THA was performed. The acetabular cups were positioned at 45° abduction and 20° anteversion, and the anteversion of femoral stems were 15°. Circular osteophytes with a 30-mm rim were built around the acetabular cup. Fourteen ADL motions were simulated, and the osteophytes were removed until there was no impingement. A clock face was used to map the location and the width of tolerable osteophytes.

Results

The impingement mainly occurred in antero-superior and posterior portions around the acetabular cup. Only 4.2 – 6.2 mm osteophytes were tolerable at the antero-superior portion (12-3 o’clock) and 6.3 – 7.2 mm-osteophytes at the posterior portion (8-10 o’clock) following a total hip arthroplasty. In antero-inferior and postero-superior portions, over-20 mm osteophytes did not induce any impingement.

Conclusion

Osteophytes in the antero-superior and posterior portion of the acetabulum should be excised during a THA to avoid impingement of the femur-stem construct on the acetabular osteophytes during ADLs.

Key Words: hip, arthroplasty, osteophyte, impingement, simulation

Introduction

Impingement between the femoral stem and the acetabular osteophytes can occur following a THA and this could lead to problems such as limitation of motion, subluxation, dislocation, damage of the acetabular liner, and excessive stress on the stem neck [1-3].

This type of impingement is influenced by multiple factors including osteophytes around the acetabular cup, the geometry of the stem neck, positions of the implants, and patient's activity [1,4,5].

The acetabular osteophytes are a common finding of osteoarthritic hips [1,3,4,6,7]. Operative principles to minimize an impingement include removal of acetabular osteophytes [1,5,8,9]. Although the location of postoperative impingement has been revealed, there is no information about the quantity of the osteophytes surgeons should remove to avoid impingement. Excessive removal of osteophytes may lead to the risk of an acetabular fracture, injury to the neurovascular structures, bleeding [10-13,7].

Previously, two simulation studies have investigated the impingement between acetabular osteophytes and femoral stem after THA. One study, which used computer-aided designs (CADs) of ten patients, showed that osteophyte removal increased impingement-free ROM [14]. Another CAD study on 4 cadaver models found that the impingement occurred in postero-inferior and antero-superior portions of the acetabulum [12]. The authors concluded osteophytes in these portions should be removed during THA. These simulations involved only a small number of hip models or only located the site of impingement [14,12]. To date, the tolerable width of osteophytes around the acetabular cup has not been defined.

We postulated that a certain amount of acetabular osteophytes in specific areas should be removed to achieve impingement-free ROM for activities of daily living (ADL). Thus, our study aimed to locate the site of the impingement after THA and to determine the tolerable width of acetabular osteophytes using a 3-dimensional (3D) simulation.

Materials and Methods

This simulation study was approved by the Institutional Review Board of our hospital.

Among 63 primary THAs (61 patients), which were performed from March to May 2015 at our institution, we recruited THAs, which were done with the use of single design prostheses, to control confounders related to prosthetic design.

Fifty-nine THAs (57 patients) were operated with the use of a hemispherical cup (Bencox® Mirabo, Corentec, Seoul, South Korea), a medium-length double tapered stem (Bencox® M stem, Corentec), and Delta ceramic bearing (CeramTec, Plochingen, Germany) (Fig. 1). In these 57 patients, preoperative CT scans of the pelvis and femur were performed routinely to plan the THA [15].

To keep the principle of statistical independence [16], we enrolled only first THA in 2 patients, who received bilateral THA. Among the 57 THAs of 57 patients, we excluded 7 hips, which had deficient CT images of the distal femur, 11 hips, which had metal artifacts due to pre-existing metal implant, and 4 hips, which had severe deformity due to previous trauma or childhood hip disease. The remaining 35 THAs (35 patients) were included in the study for evaluation.

There were 15 men and 20 women, whose age ranged from 22 to 81 years (mean, 58.0 years). The evaluated side of the hip was right in 21 and left in 14 cases. Primary diagnosis for THA was femoral head osteonecrosis in 19 hips, primary hip osteoarthritis in 4 hips, secondary arthritis in 9 hips, rheumatoid arthritis in 2 hips, and femoral neck fracture in 1 hip.

CT scans were done with the use of either a 64-slice CT scanner (Brilliance-64, Philips Medical Systems, Best, the Netherlands) or a 256-slice CT scanner (Brilliance iCT, Philips Medical Systems). The scanning parameters were as follows: 120 kV; 300 mAs; collimation, 64 * 0.625

mm (64-slice CT) or 128 * 0.625 mm (256-slice CT); rotation time, 0.5 s; A slice thickness was 2 mm (64-slice CT) or 1mm (256-slice CT). The slice interval was 1 mm (64-slice CT) or 0.5mm (256-slice CT). Abduction and anteversion of the acetabulum, acetabular diameter, femoral neck version, neck shaft angle and femoral offset were measured on preoperative CT scan by two assessors, who were not involved in the surgical procedure [15,17-20]. One assessor measured all the assessments in 20 randomly selected radiographs again with a 2-week interval between evaluations to assess intraobserver reliabilities of measurements. Intraclass correlation coefficients of intra- and interobserver reliabilities of alignment measurements were excellent, >0.85 (range, 0.89-0.95). The anterior and central osteophytes were excluded when we measured the acetabular anteversion and abduction [15]. The mean acetabular abduction was 40.4° (SD, 4.6°; range, 30.5° – 52.1°), the mean acetabular anteversion was 17.6° (SD, 4.9°; range, 2.5° – 29.2°), and the mean diameter of the acetabulum was 54.1 mm (SD, 3.6 mm; range, 46.4 mm– 61.8 mm). The mean femoral neck anteversion was 16.2° (SD, 10.8°; range, 0.1° – 39.9°), the mean neck-shaft angle was 128.8° (SD, 6.0°; range, 118.9° – 146.2°), and the mean femoral offset was 39.6 mm (SD, 6.5mm; range, 20.4 – 49.6 mm).

Mesh models of the pelvis and femur were created from the CT images using a workstation (Extended Brilliance Workspace, version 4.5.2.4031, Philips Medical Systems). The 14 left hip models were mirrored to represent a right hip. Each mesh model was obtained by manually separating the pelvis and femur on the CT scans.

Mesh models of the THA prostheses were virtual implanted on 35 hip mesh models with use of OpenMesh library [21]. The acetabular cup was a hemispherical titanium cup and the femoral stem was a tapered titanium stem, which was proximally porous-coated. It has a trapezoidal neck design to allow a wide range of motion. The neck-shaft angle of the stem was

132°. The diameter of the ceramic bearing was 28 mm, 32 mm or 36 mm. Three-dimensional mesh models of various size M stems, Mirabo cups, ceramic heads, and ceramic liners were obtained from the manufacturers (Table. 1).

Anterior superior iliac spine, posterior superior iliac spine, pubic tubercles, anatomical axis of the femur, posterior condyle and epicondyle of distal femur were manually selected and registered as reference points for the construction of the coordinate system. In each of the 35 virtual THAs, 3D implant models were inserted using both cross-sectional and 3-dimensional images. The 3D models had the same size with the prostheses, which were implanted in real THAs.

During the virtual surgery, the anterior pelvic plane was oriented vertically [22]. The acetabulum was reamed to the floor of the cotyloid fossa, and the acetabular cups were positioned at 45° abduction and 20° anteversion [12,14,23-25]. The femoral stems were implanted with 15° anteversion[18] (Fig. 2). All meshes of the pelvis, femur, and prostheses were aligned to form AABB (Axis-Aligned Bounding Box) data structure [26].

To visualize the virtual surgery, Qt providing cross-platform software development [27] and qglviewer library [28] were used.

After the virtual THA, the senior surgeon verified the adequacy of implant position in comparison with patients' postoperative radiographs. Circular osteophytes, which had a rim of 30 mm-width, were built around the margin of the acetabular cup (Fig. 3).

We selected 14 ADL motions, which were known to lead to hip impingement (Table 2) [22,29-31]. In the analysis of the motion of the hip, two coordinate systems for pelvis and femur, which had been proposed by the Standardization and Terminology Committee of the International Society of Biomechanics (ISB) [32], were used. The neutral position of the femur was considered to be where the femoral and pelvic coordinate frames are coincident. [13,16].

Then, we simulated these 14 ADL motions on each osteophyte model. During the simulated motions, any part of the osteophytes, which collided with the femur-stem construct, was removed until there was no collision [14]. To locate the position of impingement, the superior pole was marked as 0° position. The width of impingement-free osteophytes was measured at 360 positions of 1° interval around the acetabular cup in the 35 models. Then, the mean width of the osteophytes at each position was calculated and plotted in the acetabular model.

For practical use during the surgery, an analog clock face was overlapped on the acetabulum. The 12 o'clock position was marked as the superior pole, 6 o'clock the inferior pole, 3 o'clock the anterior pole, and 9 o'clock the posterior pole. The acetabular rim was divided into 12 sectors of 30°. The locations and the widths of the tolerable osteophytes were recorded on the clock face [33]. Statistical analysis was conducted using SPSS version 22.0 (IBM Corp., Armonk, NY, USA.).

Kolmogorov-Smirnov test was performed to evaluate normality of the tolerable widths. The level of significance was set at $p < 0.05$.

Results

In the simulation of 14 ADL motions, the acetabular osteophytes were the only structure, which collided with the stem-femur composite and limited ROM for ADL. No other bone-to-bone or bone-to-prosthetic impingement was detected.

The mean width of the tolerable osteophytes varied widely from 4.2 mm to 29.6 mm according to the location. Mean widths distributed normally, except for anteoinferior portion (4-6 o'clock), where the impingement scarecely occurred. Antero-superior and posterior parts of the acetabulum were two main locations, in which severe impingement occurred. In these 2 locations, the mean width of tolerable osteophytes was less than 10 mm; 4.2 – 6.2 mm in 12-3 o'clock and 6.3 – 7.2 mm in 8-10 o'clock in the clock face.

Based on 2 standard deviations subtraction from the mean, only 1.2mm and 1.8mm widths of the osteophytes were tolerable in anterosuperior (1-2 o'clock) and posterior portions (9-10 o'clock), respectively (Fig. 4, Table 3).

Discussion

Impingement after THA causes various problems including limitation of motion, subluxation, dislocation, damage of the acetabular liner, and excessive stress on the stem neck [1,3,2]. Although the acetabular osteophytes, which cause postoperative impingement, are traditionally removed, excessive removal of osteophytes may lead to the risk of an acetabular fracture, injury to the neurovascular structures, bleeding [10,11,7,12,13]. Thus, a question arose as to the paired information of location and width of tolerable osteophytes to avoid impingement after THA. The present study investigated the location of impingement after THA and the tolerable width of periacetabular osteophytes. To avoid impingement during motions of ADL, surgeons should remove osteophytes > 4.2 mm in antero-superior (12-3 o'clock) and > 6.3 mm in posterior portion (8-10 o'clock) following insertion of the acetabular component.

To date, several studies reported regions of impingement after THA [14,12,23,34]. Kessler et al. virtually implanted computer models of a THA design in a model of pelvis and femur in various orientations of cup abduction, cup anteversion, and stem anteversion [23]. Four head sizes ranging from 22.2 to 32 mm and two neck sizes of 10-mm and 12-mm diameter were tested. Hip ROM was reduced because of a bony impingement in 44% of their combination (1,007 of the total 2,304 contacts simulated). Although the site of impingement varied with the combination, anterior rim collided to the anterior intertrochanteric region during flexion and ischium or posteroinferior rim of acetabulum impinged to the posterior intertrochanteric region during external rotation. Kurtz et al. examined the effect of osteophyte removal by comparing ROM before and after removal of the periacetabular osteophytes [14]. They found that osteophytes between 1 and 3 o'clock caused bony impingement during flexion/internal rotation and osteophytes between 6 and 9 o'clock during extension/external rotation. Rodriguez et al.

built an osteophyte model by inflating pelvis by 1cm and compared the location of impingement with each direction of joint motion [12]. They found that impingement occurred between the osteophytes and the implants in 1 to 2 o'clock during flexion and 7 to 8 o'clock during external rotation. Overall, the previous studies agree that anterosuperior and posteroinferior quadrants of the acetabulum are two major locations of impingement after THA. However, no study evaluated the tolerable width of periacetabular osteophytes to avoid impingement. Thus, our study is the first one, which reports how much osteophytes surgeons should remove during THA.

Our study has several limitations. First, we simulated the kinematic motions with the use of single prosthetic design and single position of prostheses. The neck-shaft angle of the used stem was 132 degrees. The cup was implanted in the 45-degree abduction and 20-degree anteversion. The stem was positioned in 15-degree anteversion. The impingement is dependant on prosthetic design and component placement. Our results might be different, if other prosthetic designs were implanted in different positions. Second, we did not consider patient's spino-pelvic tilt and deformity of the acetabulum or proximal femur, which might influence the impingement during ADL motions [35]. In the present study, the coincident coordinate frames between femur and pelvis was defined as the neutral position as the position of anatomical landmarks outside CT scanning cannot defined. Third, the sizes of heads were not identical in all the simulation. The head-neck ratio is a major determinant of impingement free ROM [36]. However, as size of ceramic head was practically dependent to cup size, which was determined by size of anatomical pelvis, adapting the head size which was used in the real operation was believed to be a reasonable simulation. Fourth, as we enrolled the patients to the study consecutively, the range of patients' age was wide from 22 to 81. As the quality and biomechanical behavior of osteophytes can be different according to patients' age, the results should be interpreted with the consideration.

Our simulation study showed that

1. Impingement between the femoral neck and the acetabular osteophytes occurs mainly in the antero-superior (12-3 o'clock) and posterior (8-10 o'clock) position of the acetabulum in ADLs.
2. A mean of 4.2 mm of osteophytes should be removed in the anterior-superior portion (12-3 o'clock) and a mean of 6.3 mm in posterior portion following implantation of the acetabular component in a THA to avoid impingement.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: One of the authors was an Educational Consultant of Stryker & Smith and Nephew and got a grant from Bone Therapeutics.

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Figure Legends

Fig. 1 A hemispherical titanium cup, a tapered titanium stem and a ceramic-on-ceramic bearing were used in this study.

Fig. 2 (A) Mesh models of the pelvis and femur were created from the CT images, and mesh models of the THA prostheses were virtually implanted on hip mesh models. (B) The acetabular cups were positioned at 45° abduction and 20° anteversion, and (C) the femoral stems were implanted with 15° anteversion.

Fig. 3 A circular osteophytes, which had a rim of 30 mm-width, was built around the margin of the acetabular cup.

Fig. 4 The mean (solid line) and 1 standard deviations (dotted lines) of tolerable acetablar osteophytes. Antero-superior and posterior parts of the acetabulum were two main locations, in which severe impingement occurred.