Computerized Virtual Surgery Demonstrates Where Acetabular Rim Osteophytes Most Reduce Range of Motion Following Total Hip Arthroplasty

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Abstract *Background:* Acetabular osteophytes are common findings during total hip arthroplasty (THA). *Purpose:* This study was designed to determine the extent to which osteophytes may limit range of motion (ROM) and in which locations impingement is likely to occur if osteophytes are not removed during surgery. *Methods:* Computer-aided design was used to compare ROM of a modern hip implant in four cadaver models with and without 10-mm acetabular rim osteophytes added. A clock face, with 12 o'clock at the superior pole of the right acetabulum, was used to map impingement. *Results:* The osteophyte model limited ROM in flexion (101° v. 113° , $p=0.03$), 90° of flexion with internal rotation (16.7° v. 31.6° , $p=0.01$), and external rotation (30.4° v. 49.5° , $p=0.01$). Impingement occurred between 7 and 8 o'clock in external rotation and 1 and 2 o'clock in the other two motions. *Conclusions:* Osteophytes in these positions have the greatest impact on ROM and should be removed during THA.

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Introduction

Dislocation continues to be a significant problem following total hip arthroplasty (THA) with an accepted incidence of 2–4% [10, 12, 13, 19, 22, 28]. Factors related to dislocation include surgeon and hospital volume [11, 15, 16], component malposition [1, 9, 10, 21, 28], head/neck ratio [3, 5, 17, 24], and neck geometry [4].

Another known cause of dislocation is the presence of osteophytes that protrude beyond the edge of the acetabular cup [27]. Acetabular osteophytes are commonly found during THA for osteoarthritis, and it has been shown that among several factors, acetabular osteophytes were the most strongly correlated with the progression of osteoarthritis in the hip [29]. These osteophytes have been implicated in the etiology of hip pain and development of osteoarthritis secondary to pincer femoroacetabular impingement [6, 7, 14, 20]. Osteophytes also play a role in hip dynamics after THA as they have the potential to limit the primary arc range (ROM) in certain planes. This limitation in ROM occurs due to impingement, where the neck of the femoral component levers on the acetabular osteophyte [8, 23, 25]. This repeated strain leads to accelerated wear of both acetabular and femoral components and can lead to dislocation.

An effort is typically made intraoperatively during preparation of the cup, to remove any osteophytes that are deemed to be potential causes of postoperative impingement. However, there are no criteria for determining which osteophytes will have the greatest effect on postoperative ROM and need to be removed. The downside of gross removal of all acetabular osteophytes, regardless of size or location, is reduction of bone stock available for initial rigid fixation of the press-fit acetabular component or any potential revision surgery. Removing excess bone also increases the risk of intraoperative fracture [2]. Although rare, there is the additional risk of damage to nearby neurovascular structures or tendons.

Only a few studies have looked at the effect of acetabular rim osteophytes on ROM. One study used computer-aided design (CAD) modeling of ten patients and found that removal of osteophytes did improve ROM to impingement but only when the acetabular component was at a medialized position [18]. Another study found that in surface replacement arthroplasty, failure to remove acetabular rim osteophytes significantly limited ROM in internal rotation with 90° of flexion [26]. The authors recommended trimming the bony rim especially if it measured more than 2 mm in the anterosuperior part of the acetabulum.

The purpose of this study is to evaluate the impact of acetabular osteophytes on ROM to impingement following THA. This will be done by first computationally evaluating the range of motion of a modern hip implant in four cadavers, using computer-aided design modeling and virtual surgery. A computerized model of acetabular rim osteophytes will then be created, and the effect of adding osteophytes on ROM will be noted. The secondary objective of this study is to use collision detection analysis to evaluate and map the locations of acetabular osteophytes that are most likely to lead to post-operative impingement. There is a need to understand which locations of peripheral osteophytes are likely to lead to impingement so that surgeons can ensure their removal to prevent potential dislocation.

Materials and Methods

This study was divided into two phases. Phase 1 involved the creation of three-dimensional CAD models of four cadaveric hip joints and the computerized implantation of a modern hip implant into these models. Range of motion was subsequently tested via eight specific motions and positions of impingement were noted. Phase 2 involved the creation of a model of acetabular osteophyte impingement with further ROM testing and collision detection.

Phase 1 CT scans of four non-arthritic cadaver pelvis specimens were obtained using a 2.5-mm layer spacing (LightSpeed VCT, GE Medical Systems, Chalfont St. Giles, UK). The cadavers used had an average age of 71.4 (range, 35–92) years.

Each cadaver was reconstructed using MIMICS 10.11 (Materialise, Ann Arbor, MI) to generate a three-dimensional CAD model of the right femur and pelvis for all specimens. The reconstructions were then converted to solid CAD models using Geomagic 9.0 (Geomagic, Research Triangle Park, NC).

Three-dimensional models of Secur-Fit™ HA press-fit femoral components and Trident® PSL® acetabular components of various sizes were obtained from Stryker® (Mahwah, NJ). Three-dimensional assemblies containing the femoral stem, head, liner, and shell were created using ProEngineer Wildfire 3.0 (Parametric Technology, Needham, MA).

Two-dimensional images of the femur and pelvis were created, and each cadaver was templated by a senior orthopaedic surgeon for acetabular and femoral sizing. Shells were selected for each cadaver that best fit the anatomy without perforating the medial wall of the pelvis, and were inserted at 45° of abduction and 20° of anteversion. They were then positioned to attain circumferential coverage about the bone–shell interface. Component size was recorded for each cadaver.

Femoral components were selected using neck angle and head offset to preserve the anatomic offset of each cadaver and ensuring that the stem would adequately fill the intramedullary canal. Femoral head size was standardized to 28 mm and the stem was inserted at 15° of anteversion for all cadaver models. After selecting the appropriately sized component, the position, neck angle, and necessary head offset were recorded for each cadaver.

After templating, each cadaver underwent virtual surgery, reaming the acetabulum, and removing the femoral neck as specified by the femoral component templates. The resection on the acetabular side was performed such that adequate coverage would be attained circumferentially about the acetabular shell, without violating the medial wall of the acetabulum. The components were then implanted into the cadaver models, with placement verified by a senior orthopaedic surgeon to ensure that the models were representative of clinical practice (Fig. 1).

Eight hip motions were examined following the virtual surgery: flexion, extension, abduction, adduction, internal rotation, external rotation, flexion to 90° with internal rotation, and flexion to 90° with external rotation. A collision detection analysis was performed using a virtual simulator (VisualNastran 4D, MSC Software Corporation, Santa Ana, CA). The absolute ROM in each plane until impingement and

Fig. 1. Creation of cadaver pelvis and virtual surgery. **a** Virtual 3D cadaver pelvis suitable for virtual surgery. **b** Measured resection of acetabulum and femur. **c** Final component position restoring leg length, offset and keeping anatomic center of rotation.

Fig. 2. Creation of the acetabular osteophyte impingement model. **a** A sphere was fit into the native cadaver acetabulum. **b** A 10-mm offset sphere was created using the original sphere as a template. **c** The “inside” sphere was subtracted along with the bulk of the outer sphere to create a 10-mm rim of osteophyte.

the position of collision on the acetabulum was recorded for each motion. To create a standard “map” for recording position of impingement, an analog clock face was superimposed over the acetabulum, with the 12 o’clock position demarcating the superior pole. The positions of impact with the acetabulum were recorded based on this clock face model.

Phase 2 Modeling software was used to create an acetabular osteophyte impingement model. First, a computer-generated best-fit sphere was implanted into the acetabulum. A 10×10-mm rim osteophyte was chosen, and the outermost point on the pelvic model was elevated by 10 mm from the surface at a perpendicular angle. The best-fit sphere was then enlarged by 10 mm. This new bigger sphere was then “protected,” while the remainder of the enlarged pelvic model was removed leaving a 10×10-mm rim around the acetabulum of each hemipelvis (Fig. 2). The eight aforementioned hip motions were then evaluated for each cadaver model, with collision detection analysis. ROM in each plane was recorded and compared to the results from phase 1 (Table 1). As in phase 1, the positions of impingement on the acetabulum were recorded using the clock face.

Statistical analysis was performed by our hospital statistician using SPSS software. Mean ROM was compared in each motion between the cadaveric and osteophyte models using paired one-tailed *t* tests, with statistical significance set as $p < 0.05$.

Results

Analysis of the data demonstrated a statistically significant decrease in ROM with the osteophyte impingement model (“OIM”) when compared to the normal cadaveric (“C”) model in five of the eight motions tested: flexion (C, $112.9^\circ \pm 2.3^\circ$; OIM, $100.9^\circ \pm 3.6^\circ$; $p = 0.033$), extension (C, $47.1^\circ \pm 0.9^\circ$; OIM, $34.1^\circ \pm 5.3^\circ$; $p = 0.033$), external rotation (C, $49.5^\circ \pm 1.5^\circ$; OIM, $30.4^\circ \pm 4.1^\circ$; $p = 0.009$), flexion in 90° with internal rotation (C, $31.55^\circ \pm 0.78^\circ$; OIM, $16.7^\circ \pm 3.6^\circ$; $p = 0.012$), and flexion in 90° with external rotation (C, $87.1^\circ \pm 1.1^\circ$; OIM, $76.3^\circ \pm 4.1^\circ$; $p = 0.038$; Fig. 3).

Mean ROM for both the cadaveric and osteophyte models was then compared to average human ROM in the aforementioned directions (Table 2). Of the hip motions where there was a significant difference between the cadaveric and osteophyte models, three fell within the range of normal physiological hip ROM: flexion, external rotation, and flexion to 90° with internal rotation.

The points at which impingement occurred between the implant and the osteophyte were recorded using a clock-face model. When mapped on the acetabulum of right-sided hip, with the 12 o’clock position as the superior pole of the acetabulum, impingement on the osteophyte was noted at the following locations: with flexion and flexion

Table 1 Summary of ROM for cadaveric and osteophyte models following computerized THA

Cadaver	F		E		IR		ER		ABD		ADD		F+IR		F+ER	
	C	O	C	O	C	O	C	O	C	O	C	O	C	O	C	O
1	119.8	111.4	48.6	35.2	125	124	48.7	24.9	57	52	37	26.8	32.8	27.1	89	87
2	120.2	96.2	48.6	48.6	125	110	51	42.7	56.8	56	31.8	32.2	33	10.4	88.8	67.4
3	112.2	99.6	46.2	27.6	131	123	52.7	25.5	63.4	59.4	30.8	25	30	15	85.8	76.6
4	111.6	96.6	45	24.8	129	129	45.7	28.6	61.2	61.2	26	22	30.4	14.4	84.4	74.4
Mean	112.9	100.95	47.1	34.05	127.5	121.5	49.5	30.4	59.6	57.2	31.4	26.5	31.5	16.7	87	76.4
STD error	2.34	3.56	0.9	5.32	1.5	4.05	1.52	4.17	1.62	2.02	2.26	2.14	0.78	3.61	1.13	4.06

All measurements in degrees

F flexion, E extension, IR internal rotation, ER external rotation, ABD abduction, ADD adduction, F+IR internal rotation in 90° of flexion, F+ER external rotation in 90° of flexion, C cadaveric model, O osteophyte impingement model

Fig. 3. Mean arc range for cadaveric model after total hip arthroplasty, acetabular osteophyte impingement model after total hip arthroplasty, and an average human male.

to 90° with internal rotation, impingement was noted between 1 and 2 o'clock on the right acetabulum (Fig. 4). In external rotation, impingement occurred between 7 and 8 o'clock on the right acetabulum.

Discussion

Dislocation is a significant complication following THA and may be caused by impingement between the femoral component and osteophytes on the acetabular rim. While it may seem beneficial to remove all of these osteophytes during surgery, this can lead to bone loss, intraoperative fracture, or damage to surrounding neurovascular structures. The goal of this study was to use computer-aided design modeling of cadaveric joints to examine the extent to which osteophytes affect postoperative ROM and to determine where the impact between osteophytes and the implant occurs.

To our knowledge, there are no other studies that have determined the specific position of acetabular osteophytes that can contribute to impingement postoperatively. However, there are a few weaknesses with our method. The size of the rim of osteophytes was chosen as 10 mm since this approximates the average size of osteophytes seen in vivo. It is possible that with larger osteophytes, other locations around the acetabulum could contribute to impingement.

Additionally, only one surgeon was involved with templating and selection of implants for virtual surgery. However, the principles used by the surgeon are detailed in this paper and can be universally applied.

There are many studies in the literature addressing the factors that affect impingement and ROM following THA, but only a few have considered the role of acetabular osteophytes. Kurtz et al. used similar computer-aided cadaveric surgery and found that a model of osteophyte removal led to significant improvement in ROM but only when the acetabular component was medialized 10 mm [18]. When the acetabular component was not medialized, bony impingement between the anterior inferior iliac spine and the greater trochanter occurred before the femoral bone and the acetabular rim made contact, negating any effect of the presence of osteophytes. However, the results of the current study demonstrated that a 10-mm rim of acetabular osteophytes significantly reduced postoperative ROM without a medialized acetabular component. In flexion, external rotation, and flexion to 90° with internal rotation, ROM was limited by the addition of acetabular osteophytes, regardless of acetabular offset.

Another objective of this study was to determine the location on the acetabulum where osteophytes were impinging with the femoral bone or implant. Although they were studying Surface Replacement Arthroplasty and not THA, Vendittoli

Table 2 A comparison of mean range of motion for cadaveric and osteophyte impingement model to average model range of motion

Motion	Average male ^a (°)	Cadaveric model (°)	Osteophyte impingement model (°)	<i>p</i>
Flexion	125	113±3.5	101±3.6	0.032
Extension	25	44.5±2.7	34±5.3	0.032
Internal rotation	40	126.3±1.7	121.5±4.1	0.09
External rotation	45	45.7±4	30.4±4.2	0.01
Abduction	45	59.1±1.3	57.2±2	0.068
Adduction	25	30.4±2	26.5±2.1	0.056
IR with flexion of 90°	31	28.6±3	16.7±3.6	0.012
ER with flexion of 90°	30	84.9±3.4	76.4±4.1	0.038

^a Luttgens and Hamilton [20], bold *p* values indicate clinical significance

Fig. 4. Clock face representation of zones of impingement in a right-sided acetabulum. The 12 o'clock position represents the superior pole.

and others found that osteophytes in the antero-superior quadrant of the acetabulum had an impact on ROM and recommended their removal during surgery [26]. Using a similar clock face map to the one used in this study, Kurtz et al. found that bony impingement occurred between 1 and 3 o'clock on the right acetabulum in flexion and internal rotation and between 6 and 9 o'clock in extension and external rotation [18]. The findings of the current study demonstrated that impingement on the acetabular rim occurred in locations similar to those previously reported. We found that the zones of impingement between the osteophytes and the implants were 1 to 2 o'clock for flexion and flexion to 90° with internal rotation and 7 to 8 o'clock for external rotation for a right THA. For a left THA, the zones of impingement would be between 10 and 11 o'clock for flexion and flexion to 90° with internal rotation and 4 and 5 o'clock for extension. This suggests that osteophytes that are approximately 10 mm in size should be removed specifically from the antero-superior and postero-inferior quadrants of the acetabulum.

Although a specific modern implant system was used, these results are generalizable for several reasons. All impingement occurred at the osteophyte-implant neck level, and would occur for components of similar size and design, regardless of implant type. Furthermore, both femoral and acetabular components were selected and inserted with the intent of restoring normal hip dynamics, using current surgical principles.

The results of our study indicate that acetabular osteophytes in the anterosuperior and postero-inferior quadrants decrease ROM and result in impingement, with the subsequent potential for component wear and dislocation. Based upon this study, we recommend removal of osteophytes specifically in these locations to maximize ROM and mitigate the potential negative effects of osteophyte removal.

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Disclosures

Conflict of Interest: Sebastian Rodriguez-Elizalde, MD, Alyssa M. Yeager, BA, Bheeshma Ravi, MD, Eduardo A. Salvati, MD have

declared that they have no conflict of interest. Geoffrey H. Westrich, MD received research grant from Stryker Orthopedics in support of the study; is a paid consultant for Stryker Orthopedics, outside the work. Joseph D. Lipman, MS is a paid consultant for Ivy Sport Medicine; employee of Hospital for Special Surgery; has the following patents: Posterior Stabilized Knee Prosthesis, Self-aligning knee prosthesis, Dual radius glenoid prosthetic component for total shoulder arthroplasty, Pelvic Positioner, Trochlear Clamp, Patella Resection Drill and Prosthesis Implantation Device; has pending patents for Constrained Condylar Knee Device, Prosthetic Condylar Joints With Articulating Bearing Surfaces Having A Translating Contact Point During Rotation Thereof, Elbow Replacement Apparatus And Methods, Expanding Cannula And Retractor Device And Methods Of Use and External fixation devices and methods of use; receives royalties payment from Mathys Inc. and Ortho Development Corp; has received travel support for travel to meetings from Chinese Orthopaedic Association, outside the work.

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