The Journal of Arthroplasty 28 (2013) 1173–1176

Contents lists available at SciVerse ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Computerized Range of Motion Analysis Following Dual Mobility Total Hip Arthroplasty, Traditional Total Hip Arthroplasty, and Hip Resurfacing

Gregory G. Klingenstein MD [a], Alyssa M. Yeager BA [a], Joseph D. Lipman MS [b], Geoffrey H. Westrich MD [a]

[a] Department of Orthopedic Surgery, Hospital for Special Surgery, New York, New York
[b] Department of Biomechanics, Hospital for Special Surgery, New York, New York

ARTICLE INFO

Article history:
Received 16 April 2012
Accepted 13 August 2012

Keywords:
total hip arthroplasty
range of motion
dual mobility
hip resurfacing

ABSTRACT

Newer arthroplasty designs claim to provide superior range of motion (ROM) and greater stability than their predecessors. However, there is no way to compare ROM of implant systems in an equivalent anatomical environment in a clinical setting. This study used computer-aided design to compare ROM after hip resurfacing, 28 mm THA, 36 mm THA, and anatomic dual mobility (ADM) THA in 3D models of 5 cadaver pelvises. ROM to impingement was then tested in 10 different motions and a one-way ANOVA was used to compare results. The hip resurfacing resulted in restricted ROM compared to the other 3 models in all motions except adduction. The ADM, 36 mm, and 28 mm THA resulted in similar ROM. Dual mobility constructs provide comparable ROM in patients where large head THA is not appropriate.

Hip instability remains the most common cause of revision following total hip arthroplasty (THA) in the United States [1]. In addition to surgical technique, patient factors including hip fracture, osteonecrosis, dysplasia, prior revision, and neuromuscular disease may predispose to dislocation [2]. In the early part of the last decade, surgical options for these patients were limited. Furthermore, constrained implants were used with limited long-term success [3]. More recently, large femoral heads have been utilized to obtain greater range of motion to prosthetic impingement. Metal on metal THA and hip resurfacing became increasingly common as surgeons took advantage of the increased stability provided by large diameter bearings. However, with the potential for adverse local soft tissue reaction related to metal ions and the advent of highly cross-linked polyethylene, some authors have suggested using dual mobility technology in younger, active patients [4–6].

Dual mobility total hip arthroplasty bearings have been utilized since the 1970s for increased range of motion in THA, and as an alternative to constrained liners [7]. The design is a modification of a non-constrained tripolar construct. They consist of a porous-coated monoblock acetabular component with a highly polished metal inner surface. This articulates with a large diameter polyethylene bipolar head that captures a standard 28 mm head. Studies have shown greater stability and increased range of motion with dual mobility THA compared to conventional THA, and this implant design has the potential to decrease liner wear [8]. However, there are potential downsides to this type of implant design, including the added risk of intraprosthetic dislocation and reported problems with initial fixation [9].

The purpose of this study was to determine the theoretical range of motion before bony or prosthetic impingement of an Anatomic Dual Mobility (ADM) acetabular cup, as compared to a traditional THA, using computer assisted design modeling. Additionally, the range of motion was then compared to that of other implant systems with increased bearing diameters: large head THA and hip resurfacing. Our hypothesis was that the ADM prosthesis would provide the greatest range of motion with less impingement.

Materials and Methods

CT scans of five cadaver femurs and acetabuli were obtained and segmented using Mimics 13.1 , (Materialise, Leuven, Belgium). There were four male and one female specimens. All were normal morphology without significant hip arthrosis. For each model, a total hip replacement, hip resurfacing, and Restoration ADM acetabular component (Stryker, Mahwah, NJ) were implanted in this virtual 3-dimensional environment. The implants were generated from CAD files provided by the manufacturer. The size of each femoral and acetabular component was selected based on the best fit for each individual cadaver anatomy. For the THA model, stem sizes ranged from 8–10 (Secure-fit Max, Stryker), acetabular cup sizes ranged from 50–54 mm (Trident PSL, Stryker), and 28 mm and 36 mm heads were utilized. In the hip resurfacings (Cormet, Corin, England), sizing was based on the head-neck junction geometry, using the smallest acetabular component available, 52-56 mm (Table). Abduction and

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2012.08.017.

Reprint requests: Geoffrey H. Westrich, MD, 535 East 70th Street, New York, NY 10021.

0883-5403/2807-0024$36.00/0 – see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.arth.2012.08.017

Table
Age, Gender, Race, Height, and Implant Sizes for Each Cadaver.

					ADM		Cormet		Trident PSL	
	Age	Gender	Race	Height	Shell Diameter	Liner Diameter	Head Diameter (Size)	Shell Diameter	Shell Diameter	Hip Size
Cadaver 1	65	Female	Caucasian	5′5″	50	44	46 (size 5)	52	50	127 size 9
Cadaver 2	70	Male	Caucasian	5′10″	56	50	50 (size 7)	56	54	127 size 10
Cadaver 3	92	Male	Caucasian	5′10″	56	50	48 (size 6)	54	54	132 size 9
Cadaver 4	92	Male	Caucasian	5′0″	54	48	50 (size 7)	56	50	127 size 8
Cadaver 5	35	Male	Caucasian	5′11″	52	46	48 (size 6)	54	52	132 size 9

anteversion were set to 45° and 20° with respect to the anterior pelvic plane for cup positioning in the THA and resurfacing models. The center of rotation, leg length and offset for each construct was accurately reproduced based on the original cadaver hip (Fig. 1).

The dual mobility acetabular component (ADM, Stryker) used has an asymmetric rim designed to match a native socket. There is a cut out for the iliopsoas tendon designed to reduce iliopsoas/cup rim impingement. Posteriorly, the rim of the cup is extended beyond 180 degrees of coverage increasing the jump distance to provide additional protection against dislocation. As per the recommended surgical technique, placement of the ADM cup was customized based on the location of the psoas notch of the individual cadaver anatomy. ADM component placement was within 5 degrees of the ideal alignment for abduction and anteversion. Cup outer diameters were consistent with those used for the traditional THA. The highly crosslinked polyethylene bipolar head sizes ranged from 44–50 mm.

Range of motion was tested (Visual Nastran 4D, MSC Software, Santa Ana, California) in nine different trials: flexion, extension, abduction, adduction, internal and external rotation with neutral flexion, internal and external rotation at 90° of flexion, and external rotation with 20° of extension (Fig. 2). Any bony, prosthetic or combined impingement signified the limit of motion. Mean results were compared using one way analysis of variance testing, with α set at 0.05.

Results

There were significant differences between groups in flexion ($P<0.001$), extension ($P=0.012$), internal rotation ($P<0.001$), external rotation ($P=0.01$), abduction ($P=0.004$), internal rotation with 45° flexion ($P<0.001$), internal rotation with 90° flexion ($P<0.001$), external rotation with 90° flexion ($P<0.001$), and external rotation with 20° of extension ($P=0.002$). The only motion which did not show any significant differences between groups was adduction ($P=0.998$), so no post hoc testing was done.

Post hoc tests showed that the Cormet hip resurfacing showed significantly lower range of motion than 28 mm THA, 36 mm THA, and ADM THA in every motion, with the exception of abduction. In abduction, the hip resurfacing model did not have significantly lower motion than the 28 mm THA ($P=0.065$).

Combined motion experiments with the resurfacing simulation were impossible because it did not achieve the minimum 90 degrees flexion.

In straight flexion, extension, internal rotation, external rotation, and internal rotation with 45° flexion, mean range of motion was not statistically different between the dual mobility cup, 36 mm head THA, and 28 mm head THA (Fig. 3).

In internal rotation with the hip at 90° of flexion, the ADM had statistically greater motion than the 28 mm THA ($P=.01$), but not greater than the 36 mm head. In a direct comparison, the difference in ROM between the 28 mm and 36 mm heads were not statistically different. External rotation in 90° of flexion and external rotation in 20° of extension both yielded similar results for the dual mobility and traditional THA bearing couples.

Discussion

The evolution of hip arthroplasty implants has produced numerous claims of technological advancement: some real, some perceived, and occasionally some even harmful. Newer arthroplasty designs have claimed to provide superior range of motion, and thus improved stability over 28 mm THA. The aim of this study was to compare

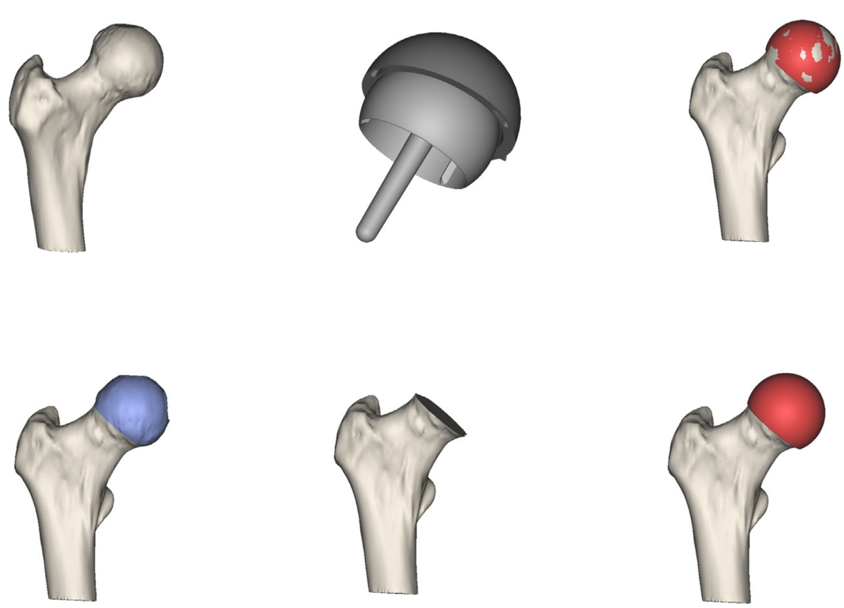

Fig. 1. Workflow demonstrating the placement and sizing of a femoral component during hip resurfacing with computer-aided design.

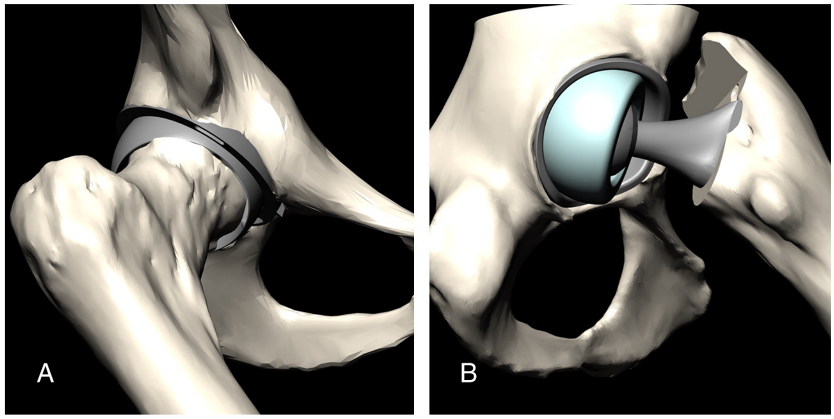

Fig. 2. Range of motion analysis showing implanted hips approaching impingement with (A) hip resurfacing and (B) dual mobility THA.

traditional 28 mm THA with 3 newer arthroplasty designs featuring larger femoral heads: 36 mm head THA, hip resurfacing arthroplasty, and dual mobility articulation. We employed computer-assisted design, which has been successfully used in prior studies to evaluate the impact of increasing femoral head size and stem neck geometry in THA [2]. We hypothesized that the dual mobility construct would provide superior range of motion to impingement than the other implants tested in our computer model of hip arthroplasty.

This 3-D computer simulation study based on human cadavers has shown dual mobility THA to provide equivalent range of motion to a 36 mm conventional THA and equal or superior range of motion to 28 mm THA. Short and medium-term outcomes in the literature are consistent with our biomechanical testing. Dual mobility bearing surfaces are new to the United States market, but have a proven record in Europe. Langlais et al. reported on 88 implanted dual mobility cups for revision THA, with two to five year follow-up [10]. They reported only one dislocation with an overall cup survival of 94.6% at five years. Guyen published results for 54 patients at risk for recurrent dislocation, treated with dual mobility implants. At mean 4-year follow-up, stability was restored in 51 patients. Of the three recurrent dislocators, two had intraprosthetic dislocation with the metal head dislodging from the polyethylene component [11]. Dual articulation cups have also been used for primary THA with cumulative survival of $95.9 \pm 4.1\%$ 19 years postoperatively, as reported by Philippot et al. [7].

Findings of the current study are supported by a recent biomechanical study of unconstrained tripolar implants in a saw bone model [12]. The prior study utilized one standard pelvis, as opposed to 5 cadaver models, and showed a significant gain in motion in flexion, extension, adduction, and internal rotation. By comparison, our computer simulation only showed modest gains for flexion and internal rotation going from a 28 mm THA to the dual mobility construct. These different conclusions are likely due to variations in implants, study design, and statistical analysis between the two experiments. A recent 3-d model comparison of 8 different resurfacing designs showed the implants lacked 31–48 degrees of motion, as compared to traditional THA counterparts. Our results are consistent with the prior report, in that three of five cadaver models with surface replacements could not reach 90 degrees of flexion.

A main strength of this study is the accuracy of computer assisted design. CAD has been successfully used and validated for THA motion analysis in numerous past multiple past studies. We used CAD files of

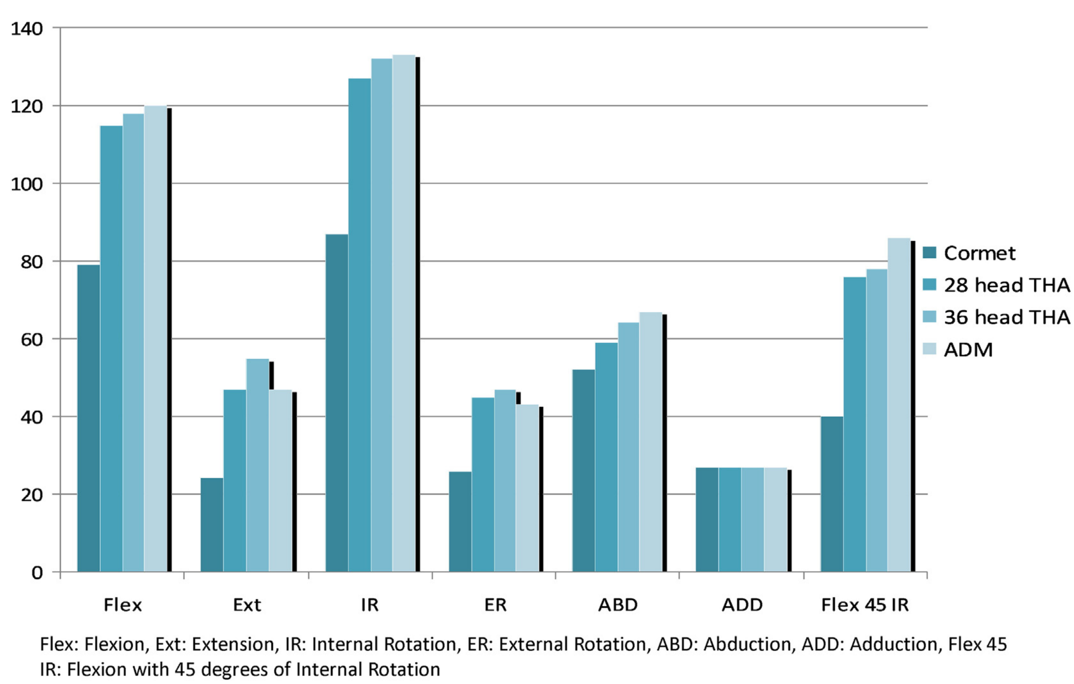

Fig. 3. Graph comparing computer-calculated range of motion to impingement in each of the motions studied for hip resurfacing, 28 mm THA, 36 mm THA, and dual mobility THA.

commonly used implants, provided by the manufacturer, as opposed to generic designs. The cadaver models were derived from CT scans, utilizing the same software used for custom implants in our institution. Range of motion in clinical practice is a measure of multiple factors including component design, offset, component positioning, bony impingement, and soft tissue impingement. By using the same cadaver models, with consistent implant positioning, we tried to account as best as possible for inter-subject variability. To our knowledge, this is the first report of computer simulation for a dual mobility cup in a cadaver model.

The main weakness of this study was the lack of soft tissue as a factor in determining range of motion. Motion in clinical practice will thus be less than reported ex-vivo. Also, the relatively small sample size may have hidden possible type II errors. Finally, the etiology of hip dislocation is multifactorial, and this study did not attempt to model extreme muscle forces or soft tissue imbalance. Hip arthroplasty stability is a combination of neuromuscular control and jump distance, as well as ROM to impingement. Thus, the computer model cannot predict actual dislocation risk in clinical practice.

In the current study, the simulations using an ADM prosthesis yielded equal or superior ROM in all tests compared with the 28 mm THA. As expected, the resurfacing arthroplasty, with a poor head neck ratio, exhibited restricted range of motion to impingement. The greatest gains with the dual mobility construct were observed in internal rotation at 90 degrees of flexion — the prime mechanism for posterior dislocation after a posterolateral approach. This finding suggests a potentially more stable implant system, but equivalent in our testing to the 36 mm THA. However, in smaller acetabuli for which 36 mm heads may be inappropriate, the dual mobility liner provides a larger effective head size, thereby increasing jump distance. This range of motion simulator data should be used along with polyethylene wear rates, and eventually clinical data, to evaluate this novel implant concept.

References

1. Bozic KJ, Kurtz SM, Lau E, et al. The epidemiology of revision total hip arthroplasty in the United States. JBJS 2009;91:128.
2. Padgett DE, Lipman J, Robie B, et al. Influence of total hip design on dislocation: a computer model and clinical analysis. Clin Orthop Relat Res 2006;47:48.
3. Shrader MW, Parvizi J, Lewallen DG. The use of a constrained acetabular component to treat instability after total hip arthroplasty. J Bone Joint Surg Am 2003;85:2179.
4. Aroukatos P, Repanti M, Repantis T, et al. Immunologic adverse reaction associated with low-carbide metal-on-metal bearings in total hip arthroplasty. Clin Orthop Relat Res 2010;468(8):2135.
5. Barrett WP, Kindsfater KA, Lesko JP. Large-diameter modular metal-on-metal total hip arthroplasty: incidence of revision for adverse reaction to metallic debris. J Arthroplasty 2012;27(6):976.
6. Kluess D, Zietz C, Lindner T, et al. Limited range of motion of hip resurfacing arthroplasty due to unfavorable ratio of prosthetic head size and femoral neck diameter. Acta Orthop 2008;79(6):748.
7. Philippot R, Camilleri JP, Boyer B, et al. The use of a dual-articulation acetabular cup system to prevent dislocation after primary total hip arthroplasty: analysis of 384 cases at a mean follow-up of 15 years. Int Orthop 2009;33(4):927.
8. Stroh A, Naziri Q, Johnson AJ, et al. Dual mobility bearings: a review of the literature. Expert Rev Med Devices 2012;9(1):23.
9. Lyons MC, MacDonald SJ. Dual poly liner mobility optimizes wear and stability in THA: opposes. Orthopedics 2011;34(9):e449.
10. Langlais FL, Ropars M, Gaucher F, et al. Dual mobility cemented cups have low dislocation rates in THA revisions. Clin Orthop Relat Res 2008;466(2):389.
11. Guyen O, Pibarot V, Vaz G, et al. Use of a dual mobility socket to manage total hip arthroplasty instability. Clin Orthop Relat Res 2009;467(2):465.
12. Guyen O, Pibarot V, Vaz G, et al. Unconstrained tripolar implants for primary total hip arthroplasty in patients at risk for dislocation. J Arthroplasty 2007;22(6):849.