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Radiostereometric Analysis Study of Tantalum Compared with Titanium Acetabular Cups and Highly Cross-Linked Compared with Conventional Liners in Young Patients Undergoing Total Hip Replacement

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Background: Radiostereometric analysis provides highly precise measurements of component micromotion relative to the bone that is otherwise undetectable by routine radiographs. This study compared, at a minimum of five years following surgery, the micromotion of tantalum and titanium acetabular cups and femoral head penetration in highly cross-linked polyethylene liners and conventional (ultra-high molecular weight polyethylene) liners in active patients who had undergone total hip replacement.

Methods: This institutional review board-approved prospective, randomized, blinded study involved forty-six patients. Patients were randomized into one of four cohorts according to both acetabular cup and polyethylene liner. Patients received either a cementless cup with a titanium mesh surface or a tantalum trabecular surface and either a highly cross-linked polyethylene liner or an ultra-high molecular weight polyethylene liner. Radiostereometric analysis examinations and Short Form-36 Physical Component Summary, Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), University of California Los Angeles (UCLA) activity, and Harris hip scores were obtained preoperatively, postoperatively, at six months, and annually thereafter.

Results: All patients had significant improvement ($p < 0.05$) in Short Form-36 Physical Component Summary, WOMAC, UCLA activity, and Harris hip scores postoperatively. On radiostereometric analysis examination, highly cross-linked polyethylene liners showed significantly less median femoral head penetration at five years ($p < 0.05$). Steady-state wear rates from one year to five years were 0.04 mm per year for ultra-high molecular weight polyethylene liners and 0.004 mm per year for highly cross-linked polyethylene liners. At the five-year follow-up, the median migration (and standard error) was 0.05 ± 0.20 mm proximally for titanium cups and 0.21 ± 0.05 mm for tantalum cups.

Conclusions: In this young population who had undergone total hip replacement, radiostereometric analysis showed significantly less femoral head penetration in the highly cross-linked polyethylene liners compared with that in the

continued

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conventional ultra-high molecular weight polyethylene liners. Penetration rates were one order of magnitude less in highly cross-linked polyethylene liners compared with ultra-high molecular weight polyethylene liners. There was no significant difference in proximal migration between the tantalum and titanium acetabular cups through the five-year follow-up ($p > 0.19$).

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

In the active population undergoing total hip arthroplasty, limiting polyethylene liner wear and maintaining acetabular cup stability are crucial to preventing premature implant failure and subsequent revision. The most common causes for revision total hip arthroplasty in the United States are instability and/or dislocation and mechanical loosening¹. International registries have identified component loosening as the most common reason for short-term and intermediate-term revision total hip arthroplasty^{2,3}.

The cellular-mediated inflammatory response to polyethylene liner wear debris is thought to be the primary mechanism leading to periprosthetic osteolysis and aseptic loosening^{4,5}. The measurement of femoral head penetration, as an indicator of acetabular liner wear, provides an in vivo marker for premature

implant failure; wear rates of <0.05 mm per year are associated with a low risk of osteolysis⁵. The interest in reducing wear and wear debris in ultra-high molecular weight polyethylene liners led to the development of highly cross-linked polyethylene liners, which have demonstrated improved resistance to wear and generation of fewer wear particles both in vitro and in vivo^{6,7}. Despite improved wear properties, highly cross-linked polyethylene liners generate smaller wear particles and have reduced plasticity, reduced fatigue resistance, and reduced resistance to crack propagation, which may contribute to implant failure^{8,9}. These material property trade-offs necessitate intermediate-term to long-term evaluation of highly cross-linked polyethylene liners compared with conventional ultra-high molecular weight polyethylene liners.

TABLE I Baseline Demographic Characteristics and Preoperative Evaluation

	All Patients (N = 46)	Ultra-High Molecular Weight Polyethylene Liner and Titanium Cup Cohort (N = 11)	Highly Cross-Linked Polyethylene Liner and Titanium Cup Cohort (N = 12)	Ultra-High Molecular Weight Polyethylene Liner and Tantalum Cup Cohort (N = 11)	Highly Cross-Linked Polyethylene Liner and Tantalum Cup Cohort (N = 12)
Age* (yr)	58 ± 7	56 ± 6	59 ± 8	59 ± 8	60 ± 7
Sex†					
Male	19	3	4	6	6
Female	27	8	8	5	5
Diagnosis†					
Osteoarthritis	42	11	11	10	10
Osteonecrosis	4	0	1	1	2
BMI* (kg/m ²)	30 ± 4	29 ± 6	30 ± 4	28 ± 4	31 ± 4
UCLA activity score* (points)	5 ± 2	5 ± 2	5 ± 2	5 ± 2	4 ± 2
Harris hip score* (points)	45.2 ± 15	41.2 ± 10	46.1 ± 12	46.0 ± 18	46.0 ± 17
SF-36* (points)					
PCS	29.7 ± 8	34.1 ± 8	29.2 ± 5	29.6 ± 8	29.5 ± 10
MCS	50.6 ± 15	52.1 ± 15	54.0 ± 11	53.2 ± 18	44.5 ± 16
WOMAC*‡ (points)					
Pain	11.7 ± 4	11.6 ± 2	12.2 ± 4	11.7 ± 5	11.9 ± 5
Stiffness	4.7 ± 2	4.6 ± 1	5.0 ± 1	5.1 ± 2	4.6 ± 2
Function	40.7 ± 13	40.8 ± 8	42.1 ± 13	40.5 ± 15	37.8 ± 14
Total	57.1 ± 17	55.9 ± 10	60.0 ± 17	55.0 ± 21	52.1 ± 20

*The values are given as the mean and the standard deviation. †The values are given as the number of patients. ‡Higher WOMAC scores, ranging from 0 to 100 points, represent worse pain and more physical function limitations.

Fig. 1

Titanium cup measurement in UmRSA software using the gold standard of beads, edge detection, and cup center to define the acetabular cup segment for both wear and cup-migration measurements. Note that the femoral head can be measured with use of edge detection to identify the head center for wear measurement.

The design of cementless acetabular cups utilizes porous surface coatings to increase implant stability, to enhance osseous ingrowth, and to reduce aseptic loosening¹⁰⁻¹². Titanium fiber cups have demonstrated excellent fixation with very low rates of loosening, liner disassociation, and pelvic osteolysis up to sixteen years and a 96% survival rate at twenty years^{13,14}. Fifteen years ago, a novel porous biomaterial was developed from elemental tantalum with a unique metallic strut design resembling trabecular bone¹⁵. Compared with titanium porous coatings, tantalum cups possess higher-volume porosity (75% to 80%), a higher coefficient of friction against bone, and lower bulk stiffness, which are theorized to reduce stress shielding and enhance implant fixation¹⁵⁻¹⁷. Excellent clinical and radiographic results have been demonstrated at two¹⁸ and five¹⁹ years of follow-up. Many clinician researchers have called for detailed radiostereometric analysis (RSA) to quantify migration and to establish mechanical stability¹⁵. One RSA study showed minimal translation at two years using porous tantalum cups, but the authors recommended further long-term follow-up²⁰.

In 2005, we initiated a prospective, doubly randomized trial in forty-six patients using RSA and clinical outcome measures to examine femoral head penetration in highly cross-linked polyethylene liners compared with that in standard ultra-high molecular weight polyethylene liners in patients who underwent total hip arthroplasty; our two-year results were previously reported²¹. In the present study, we asked whether reduced penetration into the highly cross-linked polyethylene liners with no detectable difference in clinical outcomes remained valid after five years of follow-up. Additionally, we evaluated the performance of tantalum hemispheric cups compared with that of titanium hemispheric cups.

Materials and Methods

Study Design

Patient selection and surgical technique were described previously²¹; demographic characteristics and preoperative evaluation are shown in Table I.

Patients were randomized into one of four cohorts: ultra-high molecular weight polyethylene liner and titanium cup, highly cross-linked polyethylene liner and titanium cup, ultra-high molecular weight polyethylene liner and tantalum cup, and highly cross-linked polyethylene liner and tantalum cup.

Intraoperative RSA Technique

In addition to the tantalum markers present on the femoral implant, tantalum beads (1.0-mm diameter) were inserted into the periacetabular bone (seven beads), greater trochanter (five beads), and lesser trochanter (two beads) in a dispersed arrangement to confer precise RSA measurements^{22,23}. Eighteen tantalum beads were also implanted along the periphery of each polyethylene liner. This method of intraoperative marker implantation has been validated in a prior study with no reported adverse events related to tantalum marker placement or migration²².

RSA and Clinical Evaluations

Two patients died because of medical oncology complications (acute myelogenous leukemia and metastatic non-small cell lung cancer) unrelated to their total hip arthroplasty.

RSA was performed at two weeks, six months, and yearly thereafter. Two pairs of standing, digitized RSA radiographs were obtained with use of a standard hip cage (model 43; RSA Biomedical, Umeå, Sweden) in a dedicated RSA imaging suite at the UMass Memorial Medical Center's Arthritis and Joint Replacement Center with two fixed radiograph sources. Each patient had at least one set of double examinations taken at a single visit to determine the precision of the radiographic setup. A single blinded investigator (M.G.) analyzed the pairs of radiographs using the digital software package UmRSA (RSA Biomedical).

Polyethylene wear was measured with use of point motion: penetration of the center of the femoral head into the acetabular cup. Penetration in the y-plane or proximal direction was reported. The cup segment in the titanium cohort was defined by up to six polyethylene liner beads, the cup center, and two points identified on the cup with use of edge detection (Fig. 1). Because of the inability to

TABLE II Total Femoral Head Penetration into the Ultra-High Molecular Weight Polyethylene and Highly Cross-Linked Polyethylene Liners in the Lateral, Proximal, and Axial Dimensions at Each of the Follow-up Intervals*

	Follow-up					
	Six Months	One Year	Two Years	Three Years	Four Years	Five Years
Ultra-high molecular weight polyethylene liners						
Lateral (x-axis)	0.01 ± 0.03	0.03 ± 0.02	-0.02 ± 0.03	-0.03 ± 0.05	-0.06 ± 0.05	-0.04 ± 0.04
Proximal (y-axis)	0.08 ± 0.02	0.18 ± 0.02	0.24 ± 0.02	0.33 ± 0.05	0.34 ± 0.05	0.38 ± 0.05
Axial (z-axis)	0.08 ± 0.05	0.10 ± 0.04	0.12 ± 0.05	0.22 ± 0.09	0.14 ± 0.06	0.12 ± 0.06
Highly cross-linked polyethylene liners						
Lateral (x-axis)	0.01 ± 0.02	-0.01 ± 0.01	0.01 ± 0.03	-0.04 ± 0.03	0.02 ± 0.02	0.01 ± 0.02
Proximal (y-axis)	0.06 ± 0.02	0.07 ± 0.02	0.11 ± 0.02	0.04 ± 0.01	0.09 ± 0.01	0.08 ± 0.01
Axial (z-axis)	-0.01 ± 0.05	0.02 ± 0.04	0.06 ± 0.03	0.05 ± 0.05	-0.02 ± 0.03	0.03 ± 0.05

*The values are given as the median and the standard error, in millimeters.

identify the center of the femoral head with use of edge detection in the radiodense tantalum cups, we developed and tested a novel method to assess wear data from this cohort (unpublished data). The novel fictive femoral head method was based on the identification of two radiopaque tantalum markers attached to the stem proximally and a priori knowledge of the femoral head and stem configuration of the inserted total hip replacement. A stem configuration library was created from a series of radiographs, providing geometrical information that was then used to place, in a three-dimensional space, a fictive femoral head center to be used by the RSA software.

Cup migration was measured with use of segment motion, and migration of the acetabular cup segment was compared with the fixed acetabular bone seg-

ment. The titanium cup segment was defined as described above, and the tantalum cup segment was defined with use of a beadless method, as the beads are not visible on RSA radiographs because of the dense tantalum cup. The cup center and four additional points were assigned to the tantalum cups with use of edge detection of the back of the cup and its opening (see Appendix). The maximum acceptable mean error of rigid body fitting for all comparisons was 0.25. The maximum acceptable condition number for wear measurements was 100. For cup migration, the maximum acceptable condition number was 120 in the titanium cohort and 245 in the tantalum cohort. The higher condition number was allowed in the tantalum cohort because of the lower number of points defining this segment (up to 5 points) compared with that in the titanium cohort (up to 9 points).

Fig. 2

The median femoral head penetration (and standard error) in the proximal direction was significantly higher at all time points, except at six months in the ultra-high molecular weight polyethylene (UHMWPE) cohort, compared with the highly cross-linked polyethylene (HXLPE) cohort (* $p < 0.003$). Within each cohort, there was significant change in head penetration from one to five years of follow-up ($p = 0.012$ for the ultra-high molecular weight polyethylene liner group and $p = 0.046$ for the highly cross-linked polyethylene liner group).

TABLE III Comparison of Clinical Outcomes Between Randomized Polyethylene Liner and Acetabular Cup Cohorts

	Preoperative Outcomes*	One-Year Outcomes*	Four-Year Outcomes*	Five-Year Outcomes*
SF-36 PCS†				
Ultra-high molecular weight polyethylene liner and titanium cup	34 ± 8	49 ± 9	51 ± 8	51 ± 9
Highly cross-linked polyethylene liner and titanium cup	29 ± 5	50 ± 9	46 ± 14	44 ± 10
Ultra-high molecular weight polyethylene liner and tantalum cup	29 ± 8	48 ± 9	53 ± 6	52 ± 7
Highly cross-linked polyethylene liner and tantalum cup	29 ± 10	44 ± 12	50 ± 11	48 ± 10
SF-36 MCS‡				
Ultra-high molecular weight polyethylene liner and titanium cup	52 ± 15	59 ± 4	56 ± 5	54 ± 10
Highly cross-linked polyethylene liner and titanium cup	54 ± 11	54 ± 9	50 ± 13	50 ± 16
Ultra-high molecular weight polyethylene liner and tantalum cup	53 ± 18	59 ± 6	50 ± 14	55 ± 8
Highly cross-linked polyethylene liner and tantalum cup	44 ± 16	52 ± 10	52 ± 12	54 ± 9
WOMAC†§				
Ultra-high molecular weight polyethylene liner and titanium cup	55 ± 10	8 ± 9	1 ± 2	6 ± 7
Highly cross-linked polyethylene liner and titanium cup	60 ± 17	4 ± 7	5 ± 10	3 ± 4
Ultra-high molecular weight polyethylene liner and tantalum cup	55 ± 21	8 ± 7	4 ± 4	5 ± 6
Highly cross-linked polyethylene liner and tantalum cup	52 ± 10	11 ± 14	10 ± 22	3 ± 5
UCLA activity score†				
Ultra-high molecular weight polyethylene liner and titanium cup	5 ± 2	7 ± 1	7 ± 1	7 ± 1
Highly cross-linked polyethylene liner and titanium cup	5 ± 2	7 ± 1	7 ± 1	6 ± 2
Ultra-high molecular weight polyethylene liner and tantalum cup	5 ± 2	6 ± 2	7 ± 1	7 ± 2
Highly cross-linked polyethylene liner and tantalum cup	4 ± 2	6 ± 2	7 ± 2	7 ± 1
Harris hip score†				
Ultra-high molecular weight polyethylene liner and titanium cup	41 ± 10	86 ± 12	97 ± 3	92 ± 8
Highly cross-linked polyethylene liner and titanium cup	41 ± 12	89 ± 11	92 ± 14	93 ± 8
Ultra-high molecular weight polyethylene liner and tantalum cup	41 ± 18	87 ± 10	96 ± 3	92 ± 8
Highly cross-linked polyethylene liner and tantalum cup	46 ± 17	84 ± 20	90 ± 22	91 ± 11
*The values are given as the mean and the standard deviation, in points. †The one-year, four-year, and five-year outcome values for the SF-36 PCS, WOMAC, and Harris hip scores were significantly different from preoperative values (all $p < 0.05$) as well as the four-year and five-year outcome values for the UCLA activity score ($p < 0.05$). ‡All values for the SF-36 MCS were not significantly different from preoperative values ($p > 0.05$). §Higher WOMAC scores, ranging from 0 to 100 points, represent worse pain and more physical function limitations.				

Clinical evaluation included standard patient history, musculoskeletal examination, and screening for postoperative complications. Several validated patient-reported outcome measures were administered preoperatively, postoperatively (at two weeks), at six months, and yearly thereafter: Short Form-36 (SF-36) Physical Component Summary (PCS) and Mental Component Summary (MCS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), University of California Los Angeles (UCLA) activity, and Harris hip scores.

Statistical Analysis

A power analysis revealed that a sample size of twenty patients in each group would be adequate to determine a difference in liner wear with use of RSA with a high statistical power (95%) and significance level ($p < 0.05$), based on a two-tailed t test of expected total liner wear of 0.1 mm per year among control liners compared with 0.002 mm per year among highly cross-linked liners following a standard nonelastic deformation of 0.1 mm during the first six months (considered the bedding-in period). This sample size also allowed for unexpected losses to follow-up due to study withdrawal, death, or other reasons. Statistical analysis of liner penetration and cup migration was performed with use of the Mann-Whitney test because of significant outliers, whereas the analysis of variance (ANOVA) with the Bonferroni multiple comparison test was used to compare differences in clinical outcome measures among study groups.

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Results

Baseline Data

Baseline demographic and preoperative data are presented in Table I for all four patient cohorts. Three patients were lost to follow-up before their three-year visit. On preoperative evaluation, the average results (and standard deviation) were 58 ± 7 years for patient age, 30 ± 4 kg/m² for body mass index (BMI), 5 ± 2 points for the UCLA activity score at the time of surgery (but reported a UCLA activity score of 8 to 10 points within five years of surgery), and 45 ± 15 points for the Harris hip score. Randomization was successful, demonstrating similar preoperative age, sex distribution, BMI, UCLA activity score, Harris hip score, and SF-36 PCS, SF-36 MCS, and WOMAC subscores (all $p > 0.05$). Patient randomization, follow-up status, and RSA availability for each of the four cohorts are presented in the Appendix.

Fig. 3

The median acetabular cup migration (and standard error) in the proximal direction for both tantalum and titanium cup cohorts. There were no significant differences at any time points between the cup groups.

Femoral Head Penetration

The median femoral head penetration for both the ultra-high molecular weight polyethylene liners and the highly cross-linked polyethylene liners in the titanium acetabular shells was calculated at six months and yearly thereafter through five years of follow-up (Fig. 2 and Table II). Median penetration for the ultra-high molecular weight polyethylene liner group showed a steady increase at each time point, but penetration in the highly cross-linked polyethylene liners showed only a minor increase after the six-month bedding-in period. The median penetration measurements were significantly greater in the ultra-high molecular weight polyethylene liner compared with the highly cross-linked polyethylene liner cohorts at the one through five-year follow-up (all $p \leq 0.003$). There was a significant increase in head penetration from one year to five years in both polyethylene types when testing with a paired Wilcoxon signed rank test: from a median (and standard error) of 0.18 ± 0.02 mm at one year to 0.38 ± 0.05 mm at five years in ultra-high molecular weight polyethylene ($p = 0.012$) compared with 0.07 ± 0.02 mm at one year to 0.08 ± 0.01 mm at five years in highly cross-linked polyethylene liners ($p = 0.046$). The wear rates calculated from the one to five-year follow-ups were 0.04 mm

per year for ultra-high molecular weight polyethylene liners and 0.004 mm per year for highly cross-linked polyethylene liners.

Two patients did not have suitable double examinations for the wear precision analysis. The 95% confidence interval for the precision of the wear measurements was -0.006 to 0.038 mm, indicating that the radiographic precision was not adequate enough to allow inclusion of these RSA examinations in further analysis.

Acetabular Cup Translation

The median proximal translation for both the titanium acetabular cups (Trilogy Acetabular Hip System; Zimmer, Warsaw, Indiana) and the tantalum acetabular cups (Trabecular Metal Modular Acetabular System; Zimmer) was calculated at six months and yearly thereafter through the five-year follow-up (Fig. 3). There was no significant difference between the two cups ($p > 0.19$); however, the median translation was greater at all time points for the tantalum mesh cups (except at the three-year follow-up). At the five-year follow-up, the median migration (and standard error) was 0.05 ± 0.20 mm proximally for the titanium cups and 0.21 ± 0.05 mm for the tantalum cups. Two patients with titanium

cups demonstrated over 2 mm of proximal migration at the five-year follow-up (see Appendix), causing large standard errors. On examination, neither patient had pain or limitation from the total hip arthroplasty nor had evidence of osteolysis or loosening on radiographs through the five-year follow-up. No significant outliers were seen in the tantalum cohort; however, variable small-scale migration patterns were evident (see Appendix).

In the titanium cohort, two patients did not have suitable double examinations for the cup-migration precision analysis. The 95% confidence interval for the precision of the titanium cup-migration measurements was -0.005 to 0.069 mm. Excluding the one patient without suitable double examinations, the 95% confidence interval for the precision of the tantalum cup-migration measurements was larger, from -0.028 to 0.063 mm. The median translation of the titanium cups was within the error of the radiographic setup, indicating that true motion was not measured in the majority of patients in this cohort.

Clinical Outcomes

Standardized patient outcome assessments were completed preoperatively, postoperatively (at two weeks), at six months, and yearly thereafter. The mean scores were calculated for each cohort with preoperative, one-year, four-year, and five-year scores compared in Table III. Patient activity measured by the UCLA activity score had improved at one year following surgery and remained elevated through the five-year follow-up. Patient pain and physical function (SF-36 PCS score) improved at one year following surgery, continued to improve at four years, and remained elevated at the five-year follow-up. A similar trend was seen in the Harris hip score. Patient emotional health, interpreted through the SF-36 MCS score, did not change significantly throughout the five-year follow-up ($p \geq 0.05$). WOMAC scores improved significantly ($p < 0.05$) and remained low (less pain) through the five-year follow-up. No significant difference was observed among the four cohorts at each follow-up ($p \geq 0.05$).

Discussion

In this study, separating the patients into four cohorts based upon the type of polyethylene liner and acetabular cup did not reveal any significant differences in pain or function over the five-year follow-up. These analyses show that activity, pain, and well-being were unaffected by the type of polyethylene liner or acetabular cup, and clinical gains following total hip arthroplasty were largely realized by six months following surgery, as we have previously reported²¹.

In our young population of patients who underwent total hip arthroplasty, RSA revealed significantly less femoral head penetration in the highly cross-linked polyethylene liners compared with the ultra-high molecular weight polyethylene liners at the one-year follow-up; this persisted through the five-year follow-up, at which point there was four times less penetration in the highly cross-linked polyethylene liners compared with the ultra-high molecular weight polyethylene liners. A recent meta-analysis of twelve studies with an average follow-up duration of 5.1 years found 0.23-mm less wear in the highly cross-linked polyethylene liners compared with the ultra-high molecular weight polyethylene liners, consistent with our analysis²⁴. Three other randomized controlled studies showed comparable penetration rates²⁵⁻²⁷. The difference between studies falls within the precision of the different measurement techniques

used (as high as 0.1 mm in the off-the-shelf RSA system to 0.022 in the implanted RSA marker technique)^{27,28}.

As we previously reported, a similar degree of femoral head penetration was evident through the six-month follow-up in both polyethylene liner types, representing the plastic creep-dominated phase of penetration known as bedding-in²¹. After six months, the ultra-high molecular weight polyethylene liner penetration continued to increase through the five-year follow-up, whereas the highly cross-linked polyethylene liner penetration plateaued. Any penetration after one year is thought to be dominated by wear, which is dependent upon the mechanical properties, oxidation resistance, and wear resistance of the polyethylene²⁹.

The femoral head penetration rate was one order of magnitude lower in the highly cross-linked polyethylene liners (0.004 mm per year) compared with the ultra-high molecular weight polyethylene liners (0.04 mm per year) beginning in year 2. We therefore discontinued further randomization of the polyethylene liners at the end of year 2, and, throughout the remainder of the study, all patients received highly cross-linked polyethylene liners.

RSA cup-migration analyses in this study were also influenced by the tantalum cup use. The gold-standard RSA method was utilized for the titanium cup cohort, and a beadless edge-detection technique was implemented for the tantalum cup cohort³⁰. We used the more precise gold-standard method (95% confidence intervals) that allowed the analyses to incorporate the most radiographic information available. Although the beadless edge detection was less precise, this technique was the best option for measuring radiodense cups.

The RSA examination showed no significant difference in migration in tantalum cups compared with titanium cups through a five-year follow-up. However, there was a trend toward greater migration in the tantalum cups. The tantalum difference was evident as early as six months after surgery and persisted through five years—except for the three-year follow-up, at which titanium cup migration was found to be greater. Kärrholm and Snorrason reported that migration over two years was comparable with cemented cups³¹. The only published RSA study that we are aware of that compared migration in patients randomized to receive either titanium cups (Trilogy) or Trabecular Metal cups found no significant difference in longitudinal migration at two years³⁰. A systematic review comparing studies using RSA to measure acetabular cup migration found that every millimeter of proximal migration increased the rate of revision surgery at ten years after total hip arthroplasty³².

Including the two titanium outliers, no implants were loose on radiographs, there was no evidence of osteolysis, and no revisions were needed through the five-year follow-up. Although there was proximal motion of the acetabular component in the two titanium outliers, both patients were doing well clinically according to patient-recorded outcomes that showed improved function and excellent pain relief. They will continue to be monitored closely by clinical and radiographic follow-up. Trilogy titanium mesh and Trabecular Metal cups showed excellent fixation, similar to the findings in other reports^{2,19,33-35}.

Appendix

Figures showing tantalum cup measurement in UmRSA software with use of the beadless edge-detection technique to define the acetabular cup segment for cup-migration measurements, the

allocation of randomized patients, Trilogy titanium acetabular cup proximal translation in millimeters for individual patients, and Tantalum acetabular cup proximal translation in millimeters for individual patients showing variable small-scale migration patterns are available with the online version of this article as a data supplement at jbsj.org. ■

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