2.5 Alumina Ceramic-Ceramic Total Hip Arthroplasty using Computer-Assisted Surgical Navigation and a New Minimally Invasive Technique

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Introduction

Proper component positioning, preservation of the soft tissue surrounding the hip, and minimization of wear are three critical components for optimizing outcome following total hip arthroplasty. The current manuscript describes methods of ensuring proper component positioning using surgical navigation and a new tissue preserving minimally invasive surgical technique, both used in combination with alumina ceramic-ceramic total hip arthroplasty.

Improper component positioning has been shown to increase the incidence of dislocation following total hip arthroplasty and to increase the rate of wear and wear induced osteolysis. Proper acetabular component positioning is especially challenging because pelvic position is not accurately known during surgery and pelvic position changes significantly during surgery. Further, intraoperative radiographs are often deceiving since these views are rarely truly antero-posterior with significant malrotation about the longitudinal and transverse axes.

Surgical navigation offers the ability to track component position accurately with system accuracies within 1mm and 1 degree. While image-free hip navigation based on percutaneously digitized landmarks can be unreliable, with large and unquantifiable errors potentially introduced at surgery, surgical navigation based on CT or intraoperative fluoroscopic images can be very efficient and accurate, adding very little time, if any, to the surgery and ensuring that components are placed in acceptable position (DiGioia, Murphy).

While at first glance, less invasive techniques, may only offer short term, but no long term benefit, the principle of preserving all of the important structures around the hip joint is well founded. The principle of tissue preservation may facilitate early recovery because these methods are also minimally invasive, but the greatest benefit may be in the long term for hip joint stability, muscle strength, and the more normal state of the soft tissues surrounding the joint at the time of any revision procedure.

The use of alumina ceramic-ceramic bearings is similarly logical and appropriate. Wear debris and debris-associated osteolysis are the most common problems affecting total hip arthroplasty. Of the three types of bearings developed to reduce wear, alumina ceramic-ceramic bearings have the greatest scientific and clinical support. The other two methods include metal-metal bearings and metal-cross linked polyethylene bearings. Ironically, while cross linked polyethylene is used most commonly, it has the shortest clinical experience (only since 1998) and the highest wear. Preliminary studies have shown measureable and only slightly improved wear (Digas). One prospective study has shown a modest (50%) reduction in wear (Martell) whereas hard bearings have shown wear reduction of more than 1,000 fold. These bearings are also still susceptible to scratching and third body debris (Endo, Fischer) and clinical examples of osteolysis have been reported for both electron beam (Reis) and gamma irradiated polyethylene bearings.

By contrast, alumina ceramic bearings have been in clinical use for more than 20 years and clinical retrievals have show linear wear rates that are 4,000X less than metal-on-polyethylene bearings of the same era (Dorlot). These bearings have consistently shown low wear rates in laboratory evaluations as well as clinically (Bizot, Boutin, Garino, Murphy). Hamadouche et al had no cases of osteolysis in un-cemented ceramic-ceramic THA's at minimum 18.5-year follow up (Hamadouche).

This current manuscript reports on the results of a prospective study of alumina-alumina bearings in total hip arthroplasty, a subset of these arthroplasties performed with computer-assisted surgical navigation, and a subset performed with both tissue-preserving, minimally-invasive techniques combined with surgical navigation.

Materials and Methods

261 total hip arthroplasties in 237 patients were performed by a single surgeon using an alumina ceramic-ceramic bearing (Wright Medical Technology, Arlington, TN and Biolox Forte XLW acetablular liners and femoral heads by Ceramtec AG, Plochingen, Germany, Figure 1). Of these, 148 were performed using computer-assisted surgical navigation and 72 were performed using a combination of computer assistance and a tissue-preserving, minimally invasive technique.

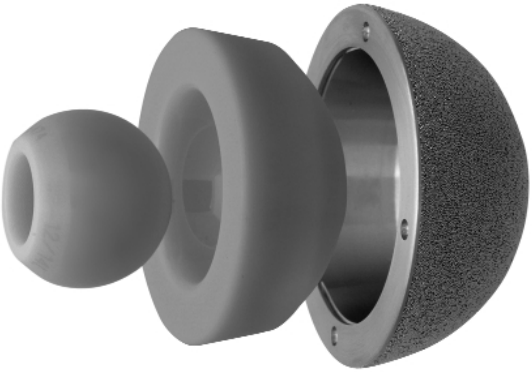

Figure 1:
The alumina-alumina bearing (Wright Medical Technology, Memphis, TN and Ceramtec AG, Plochingen, Germany).

Overall, there were 128 left hips and 133 right hips. 143 were performed in men and 108 were performed in women. Mean patient age at surgery was 50.7 years (Range: 17 years – 74 years). Patients operated upon prior to February 3, 2003 were part of an FDA/IDE study. The protocol called for patients to be evaluated clinically and radiographically twice in the first year and annually thereafter.

148 of these procedures were performed with surgical navigation either based on preoperative CT imaging (BrainLAB, Germany) or intraoperative fluoroscopy. No procedures were performed using imageless navigation since accuracy cannot be assured intra-operatively with imageless hip navigation methods. Of these 148 procedures, 72 were performed using fully tissue-preserving surgical techniques.

Design of Tissue Preserving Total Hip Arthroplasty Techniques

Design of any minimally invasive total hip technique requires decisions regarding patient position, dependence on or independence from imaging and or traction, the ability to perform a trial reduction, and the tissue intervals to be used to avoid releasing important structures.

Patient Position: The lateral position was chosen for several reasons. With the lateral position, gravity facilitates separation of the subcutaneous tissue layers and the posterior borders of the gluteus medius and medius are easily visualized. Further, this position is the most common position THA used in the United States and so surgeons who adopt this method will be able to transition the surgery into a familiar, conventional technique if any aspect of the surgery cannot be adequately managed through a more limited tissue interval.

Tissue Intervals: Since the gluteus medius, gluteus minimus, psoas, tensor fascia femoris, and rectus femoris muscles and posterior capsule are critical to hip joint function and stability, any tissue preserving surgical technique for THA must be performed without disturbing these structures. Specifically, components must be inserted either posterior, anterior, or inferior to the gluteus medius and minimus. Splitting or releasing the origin or insertion of the gluteus medius or gluteus minimus is not tissue preserving by definintion. Similarly, the posterior capsule is so essential to hip joint stability that posteriorly-based exposures involving release and repair of these structures are not tissue preserving, no matter how small the incision. Further, posterior displacement of the femoral head out of the acetabulum requires such disruption of these structures, that the femoral head cannot be posteriorly dislocated during surgery, but rather, must be either excised or dislocated anteriorly.

Anterior exposures such as the Watson-Jones and the Smith-Petersen exposures provide excellent visualization of the acetabulum but poor exposure of the femur. Performing the entire procedure through one of these exposures requires either some release of the anterior gluteus medius and minimus or skeletal traction. Skeletal traction has the great disadvantage that a trail reduction is either technically difficult or not performed. Since tissue tension, joint stability, and the absence of prosthetic impingement are critical factors for hip replacement surgery, especially using hard bearings, a trail reduction is essential. As a result, this procedure was designed to be performed without the use of skeletal traction.

Initially, this tissue preserving technique was performed using two exposures. The femoral component preparation and insertion were done through a superior capsulotomy, posterior to the gluteus medius and minimus, and anterior to the short external rotators and posterior capsule. The acetabular component preparation and insertion were done through a Watson Jones interval, inferior to the anterior medius and minimus and deep/lateral to the rectus femoris and psoas. Increasing experience showed that, with angled instruments, both femoral and acetabular component preparation and insertion could be performed through a single incision through a superior capsulotomy.

Description of the Tissue Preserving THA technique

The patient is placed in a lateral position and a 7.5 to 8cm incision is made starting at the tip of the greater trochanter. The skin incision can be longer in heavier patients as necessary. The gluteus maximus fibers are bluntly separated in line with their fibers to reveal the gluteus medius. The posterior border of the gluteus medius is mobilized anterior to reveal the piriformis tendon. The anterior border of the piriformis tendon is developed to reflect the piriformis posteriorly. The insertion of the piriformis is released and repaired as necessary since most uncemented femoral components require removal of the bone that the piriformis tendon inserts upon. The posterior border of the gluteus minimus muscle is developed and the minimus is mobilized anteriorly. A periosteal elevator is used to develop the interval between the minimus tendon and anterior capsule. A blunt homan retractor is placed in between the minimus and anterior capsule and a spiked homan retractor is placed in the ilium to protect the medius and minimus and fully expose the superior hip joint capsule.

A vertical capsulotomy is performed from the trochanteric fossa to the acetabular rim along the course of the piriformis tendon. An anterior capsular flap is developed by tagging the anterior capsule with a suture and incising the capsule along the femoral neck, underneath the minimus tendon and along the anterior-superior acetabular rim. The anterior blunt homan retractor is placed inside the anterior capsule around the anterior femoral neck. Another blunt homan retractor is placed inside the posterior capsule, around the posterior femoral neck. A spike homan retractor is placed in the posterior-superior ilium. These four retractors all of the retraction necessary to perform the procedure (Figure 2).

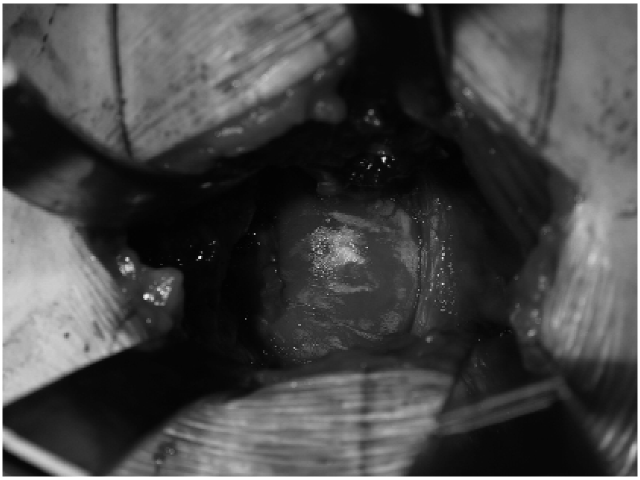

Figure 2:
Figure 2 shows the exposure of a left hip through a superior capsulotomy. The femoral head and labrum are seen in the center of the photograph. The blunt homan in the upper left is inside the anterior capsule, around the femoral neck. The spiked homan in the upper right is in the ilium, underneath the minimus and medius. The spiked homan in the lower right is inside the ilium above the posterior-superior portion of the acetabulum. The blunt homan in the lower left is inside the posterior capsule, around the femoral neck. The entire THA procedure can be performed through this exposure.

The femur is reamed through the superior femoral neck and then the superior portion of the neck is removed with an osteotome to allow the femur to be prepared with broaches. The femoral head and neck are left in situ during this part of the procedure because the head provides stability to the femur during broaching, the neck provides a fulcrum for leverage retractors, and the neck also provides reinforcement to the calcar region to reduce the likelihood of femoral fractures during femoral preparation (Figure 3).

Figure 3:
Figure 3 shows a femoral broach fully inserted through the exposure. The femur is fully prepared through the top of the femoral neck, prior to removal of the femoral head so long as the hip adducts sufficiently to allow this. The femoral head is left in place to stabilize the femur during preparation and to allow leverage retractors (blunt homans) to facilitate exposure.

Once the femur is fully prepared, a skeletal reference frame for surgical navigation is percutaneously affixed to the pelvis and leg length measurement is made. If fluoroscopic navigation is used, fluoroscopic images may be acquired at this point, or before if femoral navigation is employed. The femoral head and neck are then transected, using the blunt homan retractors to protect the surrounding soft tissues. Shanz screws are placed into the head and neck segments and they are excised. If CT based navigation is used, data points on the pelvis and acetabular are now acquired to achieve pelvic registration.

The blunt homan retractors are now placed around the acetabulum anteriorly and posteriorly in the lesser sciatic notch. The entire acetabulum can be seen and remnants of the labrum are excised. A very low profile, 45 degree angled reamer is then used to prepare the acetabulum. A z-shaped acetabular impactor is used to insert the acetabular component with assistance of surgical navigation, with the cup position generally aimed for 41 degrees of abduction and 25 to 30 degrees of anteversion (Figure 4). While acetabular screws are rarely used for fixation, if they are necessary, two methods may be used. The screws may be placed from posterior, just above the edge of the retracted posterior capsule, but this method often requires a slightly longer superficial and fascial incision. The second method allows percutaneous insertion of screws through the Watson-Jones interval, using standard hip arthroscopy cannulas and straight screw insertion instruments.

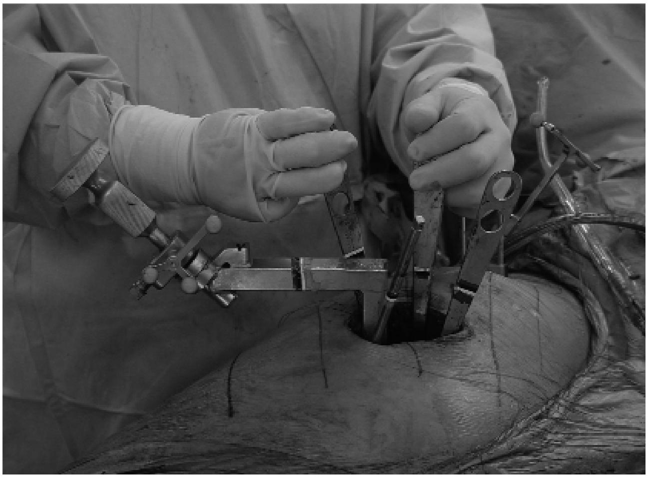

Figure 4:
Figure 4 shows the navigated acetabular impactor during cup insertion. The cup impactor is designed with two 45 degree and one 90 degree angle to allow the cup impactor to exit the incision above the greater trochanter while still allowing impaction of the cup in line with the cup axis.

After the cup is inserted, potentially impinging bone is trimmed, the trial or real alumina acetabular liner is inserted, a trial femoral head is inserted, a trial neck is affixed to the broach, and the trial neck is reduced into the trial head in situ using a bone hook for traction and maximal muscle relaxation. The head and neck are not assembled before reduction because the surrounding soft tissues are so stable that even displacement to allow reduction of a 32mm head may be difficult or cause disruption of surrounding tissues. An intraoperative radiograph may be taken to confirm proper component size and position as necessary. Trial reduction should produce a hip that cannot be dislocated in any direction without traction.

After satisfactory trial reduction, the trial components are removed, the real alumina femoral head is inserted, the real femoral component is inserted, and the femoral neck is again reduced into the femoral head in situ as before. The hip joint capsule is closed and the gluteus minimus and medius return to their native positions when the retractors are removed. The fascia overlying the gluteus maximus is closed prior to subcutaneous and skin closure (Figure 5). Postoperatively, the patient may progress motion and weight bearing without restriction.

Figure 5:
Figure 5 shows the 8.5cm incision at the completion of the procedure.
The abductors and posterior are fully intact.

Results

Of the 261 total hip arthroplasties, 60 hips have been seen at a minimum of 2 years following surgery, mean 40 months, range 26 to 72 months. The group of 261 hips overall have a mean follow up of 14.5 months. There have been three revisions. One was for failure of osseointegration of a femoral component in a necrotic proximal femur, a second was for malseating of an acetabular liner, treated by proper reinsertion of the liner, and the third was for an acetabular component that displaced at the time of surgery and recognized in the PACU which required prompt revision. Reoperations other than revision were I&D for acute infection in one, I&D without infection in one, ORIF of a post-operative greater trochanteric fracture in one, and ORIF of a greater trochanteric non union in one. There were no dislocations, no bearing fractures, and no radiographic evidence of wear or lysis.

Cup abduction angles in the total hip arthroplasties performed with computer-assisted surgical navigation averaged 41.1 degrees with a range of 35 to 49 degrees and a standard deviation of 2.3 degrees. Cup abduction angles in total hip arthroplasties performed without surgical navigation averaged 42.8 degrees with a range of 26 to 55 degrees and a standard deviation of 4.7 degrees.

Looking specifically at the tissue preserving, minimally invasive hips performed with surgical navigation, complications included one intraoperative trochanteric fracture repaired at the time of surgery, a transverse acetabular fracture during cup impaction recognized during surgery and treated successfully with protected weight bearing. The patient where the acetabular cup displaced at the time of surgery was surgery performed using the minimally invasive technique. That hip was severely dysplastic and in a patient with a body mass index of more than 35. There have been no femur fractures. Analysis of complications as a function of the number of procedures performed, all three surgical complications occurred in the first 43 procedures. The average length of stay for these patients was 3.5 days. By contrast, the patients treated by conventional surgery had a average length of stay of 4.25 days. Most dramatically concerning the use of walking aides, patients who underwent tissue preserving, minimally invasive THA had a mean score of 6.0 (SD 4.3) on a Harris Hip Scale. By contrast, patients who underwent conventional THA had a mean score of 1.86 (SD 2.96).

Discussion

The current study demonstrates that alumina on alumina tha is extremely reliable in a generally young and active patient population. The absence of osteolysis in this series is promising since osteolysis is the most common current cause of failure in total hip arthroplasty. This finding is also encouraging as reports of osteolysis with both electron beam and gamma irradiated polyethylene bearings have been reported already in bearings that have only been available since late 1998. The absence of hip dislocation in this series of 261 consecutive hip replacements is especially reassuring. Concerns that alumina ceramic bearings (with fewer available modular options such as lipped liners and or extra long heads) might lead to greater incidence of instability are clearly unfounded. This may be due, in part, to the femoral neck designs that allow for increased range of motion and the typically larger (32mm or more) bearing diameters used in many of these patients.

Bearing fracture has long been a concern with alumina –on-alumina bearings. While this issue remains a concern, the absence of bearing problems in this series is encouraging. This is especially true given the extreme demands that some of the more active patients subject their hips to. Figure 6 shows the 5 year postoperative radiograph of a patient whose hip as experienced more than 20 million cycles already, that majority of which have been high-impact running activities.

Computer-assisted surgical navigation is performed routinely now and the results of this study show that the use of this technology eliminates malpositioned acetabular cups. There is no other efficient method of achieving this goal. The pelvis moves too much during surgery for any mechanical instrument to be as accurate since the pelvic position during surgery is unknown. Similarly, intraoperative radiographs are often extremely misleading due to deviations from the AP plane.

The use of tissue-preserving, minimally invasive techniques combined with surgical navigation has had a dramatic effect on patient recovery. While length of stay has not dramatically decreased, recovery at 6 weeks is dramatically accelerated. While these techniques can be used for the vast majority of patients, significant deformities or contractures and obesity are factors that may be better addressed with conventional exposures. Of the last 30 patients who underwent primary THA, 24 were performing using minimally invasive techniques. Reasons for conventional techniques were protrusio in 2, severe anterversion from DDH in 2, achondroplasia in one, and morbid obesity in one.

From this preliminary experience, ceramic-ceramic total hip arthroplasty is extremely reliable. Component positioning can be improved with routine use of image-based surgical navigation, and recovery can be greatly facilitated in the majority of primary THA patients by the use of minimally-invasive, tissue preserving techniques.

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Figure 6:
AP radiograph of a total hip arthroplasty 5 years after implantation. The patient was 46 at the time of surgery and the hip has experienced more than 20 million, mostly high impact cycles as estimated by calculation of stride-length multiplied by distance.

References

1. Barrack R, Castro FP, Jr, Szuszczewicz ES, Schmalzried TP: Analysis of retrieved uncemented porous-coated acetabular components in patients with and without pelvic osteolysis. Orthopaedics, 25(12): 2002.
2. Bizot P, Larrouy M, Witvoet J, Sedel L, Nizard R: Press-fit metal-backed alumina sockets: A minimum 5-year follow-up study. Clin Orthop, 379:134-142, 2000.
3. Boutin P: The classic: Total hip arthroplasty using a ceramic prosthesis. Clin Orthop, 379: 3-11, 2000.
4. Dorlot JM. J. Biomed Mater Res 1989 Dec 23(A3 Suppl):299-310.
5. Digas G, Kärrholm J, Thanner J, Malchau H, Herberts P: Highly Cross-Linked Polyethylene in Hip Arthroplasty. Randomized Study Using Radiostereometry (Preliminary Report). 31st Open Scientific Meeting & 9th Combined Open Meeting of the Hip Society & AAHKS, New Orleans, Louisiana, February 8, 2003.
6. DiGioia AM, Plakseychuk AY, Levisoin TJ, Jaramaz B. Mini-incision technique for total hip arthroplasty with navigation. J. Arthroplasty. 2003 Feb/18(2):123-128.
7. Eickmann TH, Clarke IC, Gustafson GA. Squeaking in a Ceramic on Ceramic Total Hip. In Bioceramics in Joint Arthroplasty. Zippel H and Dietrich M editors. Steinkopff Darmstadt Publishers. p187-192, 2003.
8. Endo MM, Barbour PS, Barton DC, Fisher J, Tipper JL, Ingham E, Stone MH: Comparative wear and wear debris under three different counterface conditions of crosslinked and non-crosslinked ultra high molecular weight polyethylene. Biomed Mater Eng, 11(1): 23-35, 2001.
9. Fischer J, Besong AA, Firkins PJ, Barbour PSM, Nevelos JE, Tripper JL, Stone MH, Ingham E: Comparative wear and debris generation in UHMWPE on ceramic, metal on metal and ceramic on ceramic hip prostheses. 46th Annual Meeting of the Orthopaedic Research Society, Orlando, FL, March 12-15, 2002.
10. Garino JP: Modern ceramic-on-ceramic total hip systems in the United States: Early results. Clin Orthop, 379:41-47, 2000.
11. Hamadouche M, Boutin P, Daussange J, Bolander M, and Sedel L. Alumina-on-Alumina Total Hip Arthroplasty: A Minimum 18.5-Year Follow-up Study. Journal of Bone and Joint Surgery 84A(1): 69-77, 2002.
12. Heck DA, Partridge CM, Reuben JD, Lanzer WL, Lewis CG, Keating EM: Prosthetic component failures in hip arthroplasty surgery. J Arthroplasty, 10(5):575-580, 1995.
13. Mallory TH, Lombardi AV, Jr, Fada RA, Herrington SM, Eberle RW: Dislocation after total hip arthroplasty using the anterolateral abductor split approach. Clin Orthop, 358:166-172, 1999.
14. Martell J. Cross-Linkage: Another Strategy. 6th Annual Alternative Bearings Symposium, San Fransisco, September 22, 2003.
15. Murphy SB: Ceramic-ceramic bearings in THA: The new gold standard – in the affirmative. Orthopaedics, 25(9):933-934, 2002.
16. Murphy SB, Bierbaum B. Eberle RW. American Experience with Alumina Ceramic-Ceramic Bearings in Total Hip Arthroplasty. In Bioceramics in Joint Arthroplasty. Zippel H and Dietrich M editors. Steinkopff Darmstadt Publishers. p157-162, 2003.
17. Murphy SB and Deshmukh R. Clinical Results of Computer-Assisted Total Hip Arthroplasty. International Society of Computer Assisted Orthopedic Surgery. 2003.
18. Reis M. Cross-Linked Polyethylene: To be or not to be. 6th Annual Alternative Bearings Symposium, San Fransisco, September 22, 2003.
19. Timmerman I, Murphy S. Fatigue Resistance of Ceramic Liners to the Physiological Loading Under Conditions of Impingement. International Society of Technology in Arthroplasty, San Fransisco, September 24, 2003.