The Fate of Grafting Acetabular Defects During Revision Total Hip Arthroplasty

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Abstract

Background Acetabular defects are frequently grafted during revision THA. Previous studies using plain radiographs report high rates of graft incorporation. However, given plain radiographs underestimate osteolysis, it is unclear whether plain radiographs adequately reflect graft fill or incorporation.

Questions/purposes We determined if (1) graft fill; or (2) incorporation (measured as graft–bone contact) differed with complete revision and grafting compared to liner exchange and grafting; (3) defect fill and incorporation

could be assessed on plain radiographs; and (4) the cost of bone grafting differed with these two procedures.

Methods We identified 40 patients who underwent revision THA for aseptic loosening or polyethylene wear and osteolysis, either with retention of a well-fixed cup or complete acetabular revision in which bone graft was used. Lesion size, percent fill, and graft healing was quantified from CT scans. A limited cost analysis was performed using the current hospital costs for implants, bone grafts, and bone graft substitutes. The minimum followup was 1 year (mean, 4.8 years; range, 1–11 years).

Results The average defect fill was 30% (range, 0%–81%). The average percent of healing to host bone was 24% (range, 0–66%). Complete revisions had a higher percent defect fill compared to head/liner changes (47% versus 17%) as well as a higher degree of graft healing to host bone compared to head/liner changes (36% versus 14%). High resolution CT demonstrated lower percentages of defect fill and graft healing than previous reports based on plain radiographs. Bone grafting costs exceeded implant costs in the head/liner exchange group; however, the overall cost was higher in the complete revision group.

Conclusions Higher degrees of defect fill and healing were seen with complete revisions compared to head/liner exchanges. Compared to CT scans, plain radiograph assessment tended to overestimate defect fill and healing.

Level of Evidence Level III, therapeutic study. See the guidelines online for a complete description of level of evidence.

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Introduction

Revision surgery now constitutes 15–20% of hip arthroplasty procedures in the United States [34]. Revision

arthroplasty may be needed for a variety of reasons, with aseptic loosening one of the most common [8]. Osteolysis is a leading cause of aseptic loosening and can be present anywhere that has a connection to the joint [15, 31]. The supraacetabular weight bearing portion of the hip is among the most common and worrisome locations [15]. Lesions can progress in size [13, 16] leaving the patient at risk for loosening of the acetabular component, progressive bone loss, and even catastrophic failure [22].

The morbidity associated with revision THA has caused a recent surge in research aimed at preventing and treating osteolysis both surgically and medically [11, 23, 33]. With improved understanding and detection techniques, osteolysis that can result in aseptic loosening may be diagnosed and treated prior to extensive bone loss and/or acetabular component loosening [14, 19]. Bone grafting around and through retained acetabular components along with exchange of the femoral head and acetabular liner has become increasingly popular [3, 20–22, 24, 35, 36]. However, the periacetabular area can be difficult to access when the acetabular shell is well fixed, and osteolytic lesions can be difficult to identify and débride at the time of surgery [10, 21, 30]. Also, osteolytic lesions may be lined with a pseudomembrane [17, 29] that may prevent bone graft incorporation. If the membrane is not completely excised, healing can be compromised by the lack of direct contact between graft material and host bone. Two other studies demonstrated approximately 50% lesion fill, but only qualitatively described healing of the graft to host bone after grafting around and through retained acetabular components [10, 25]. Several other studies have reported high rates of graft incorporation, but have been based on plain radiographs [22, 30]. High resolution CT scans are superior to plain radiographs in assessing osteolytic defects as plain film analysis often underestimates or is unable to detect lytic lesions [19, 26]. CT examination is also a useful tool when determining the incorporation of bone grafts in other areas [1, 27].

Using CT, we (1) the percent fill and (2) the amount of incorporation in osteolytic lesions treated with head and liner exchange with bone grafting through or around the acetabular component compared to those treated with full acetabular revision with bone grafting; (3) determined the ability to judge the extent of defect fill and defect healing based on plain radiographs compared to CT measurements; and (4) determined the cost of using bone graft substitutes in revisions for osteolysis as well as whether any difference existed between the two procedures in terms of cost.

Patients and Methods

From an institutional total joint registry we identified 2727 hips in 2531 patients with 727 revision THAs in 626

patients performed from January 1, 1997 to December 31, 2007. The database consists of demographic information, outcomes scores, component type and size, and complications. Of the 626 patients, 403 (437 hips) underwent revision for a preoperative or postoperative diagnosis of osteolysis or aseptic loosening. Pre- and postrevision AP radiographs were reviewed to identify an adequately sized (greater than 2×2 cm) grafted lesion remote from the surface of the shell to allow assessment of the grafted defect. One-hundred thirty-three of the 403 patients (437 hips) met these criteria and underwent revision with retained acetabular component and head and liner exchange, while 181 patients (218 hips) were revised with full revision of the acetabular component. We excluded 102 patients (109 hips) who had no bone grafting. We contacted the remaining 212 patients for participation in the study. Thirty-eight patients (40 hips) agreed to undergo CT examination; 20 (22 hips) in the head and liner exchange group and 18 full acetabular revisions. These 40 hips (10% of the group of 401) comprised the two study groups. The average time from the index surgery to revision surgery was similar ($p = 0.83$) for the two groups: 12 years (range, 2–21 years) for the head and liner exchange group and 11.6 years (range, 3–20 years) for the acetabular revision group. The average age at time of revision was similar ($p = 0.54$): 57.1 years (range, 23–85 years) in the retained component group compared with 54.1 years (range, 25–82 years) in the revised acetabular component group. The average age at most recent followup was also similar ($p = 0.46$): 63.8 years (range, 35–88 years) in the retained component group and 60.5 years (range, 33–88 years) in the acetabular revision group. There was no difference in gender or sidedness between groups (Table 1). The minimum clinical and CT followup was 12 months (mean, 60 months; range, 12–121 months).

We used a posterior approach to the hip for both head and liner exchanges and revision of the acetabular component. Following exposure of the acetabular component the liner was removed and the stability of the bone-implant interface was assessed. In hips where the patients had no symptoms or history of instability and the component was well fixed and in reasonable position, the acetabular shell was retained and the surgeon proceeded with débridement of the region of osteolysis using curettes and then pulse lavage. Bone graft was then introduced either through the holes in the cup, around the periphery of the component, via a cortical window, or a combination of these techniques based upon the location of the lytic defect. If the acetabular component was loose the shell was removed, curetted, and the acetabulum was then reamed. Bone graft was then introduced and the reamer was placed on reverse to impact the graft.

In the head and liner exchange group there were 11 hips grafted through the screw holes only. In four patients the

Table 1. Comparison of head liner revision versus complete acetabular revision cases

Variable	n = 40 Total	n = 22 Head/liner	n = 18 Complete revision	p-Value
Lesion volume (mm ³)	11.1 ± 9.4	12.8 ± 11.3	9.0 ± 6.4	0.427
Lesion surface area (mm ²)	5.6 ± 3.0	6.0 ± 3.4	5.1 ± 2.4	0.518
% fill	30.3 ± 26.1	16.7 ± 16.1	47.4 ± 26.9	0.002
% heal	23.7 ± 19.8	14.4 ± 12.5	35.5 ± 21.6	0.005
Length followup (years)	5.0 ± 2.7	5.3 ± 2.7	4.6 ± 2.7	0.370
Age at time of revision	55.8 ± 15.0 (23–85)	57.1 ± 15.4 (23–85)	54.1 ± 14.7 (25–82)	0.538
Hip score preoperative	65.3 ± 17.9	71.3 ± 16.9	57.0 ± 16.4	0.034
Hip score postoperative	83.1 ± 16.6	84.6 ± 15.2	81.3 ± 18.5	0.618

lytic lesion was accessed and bone grafting performed around the periphery of the cup only. In one patient a cortical window alone was used to débride and graft the lytic lesion. Five patients had bone grafts through screw holes and around the periphery of the acetabular component, and one patient had a bone graft placed through a cortical window and through the holes in the cup. There were nine hips that had multiple types of bone graft or bone graft substitutes used during head and liner exchange revisions. Cancellous chips were used in 10 hips, bone putty in seven hips, pellets in five hips, cancellous cubes in four hips, MIIG kits (Injectable Calcium Sulfate, Wright Medical Technology, Inc, Arlington, TN, USA) in three hips, and BMP (INFUSE, Medtronic Sofamor-Danek, Minneapolis, MN) in three hips.

In the revised acetabular component group 10 hips received multiple types of bone graft or bone graft substitutes; eight hips had morselized femoral head allograft, with a total of 14 femoral heads used; nine hips had cancellous cubes; seven hips had cancellous chips; four hips used Allomatrix (Wright Medical Technology, Inc, Arlington, TN, USA) putty; and one hip used BMP. Using the current contracted prices at our hospital, we determined the hospital cost of the graft material, heads, liners, and acetabular shells. This was not a complete cost analysis as operative time and the differences in costs associated with operating room use and anesthesia were not included.

In the group with head and liner exchange only, there were nine Longevity liners (Zimmer, Inc, Warsaw, IN), four Zimmer standard PE liners (Zimmer, Inc, Warsaw, IN), one Exactech (Exactech, Inc, Gainesville, FL), one DuraLoc (DePuy Orthopaedics, Inc, Warsaw, IN), one S-ROM (DePuy Orthopaedics, Inc, Warsaw, IN), and six Reflection (Smith and Nephew Orthopaedics, Inc, Memphis, TN) liners implanted. Ten liners were cemented by roughening the metallic and polyethylene surfaces using a metal-cutting burr prior to cementation. Twelve acetabular components had intact locking mechanisms and a modular liner was locked into place in the standard fashion. In the

acetabular revision group, the acetabular components were revised to Trabecular Metal cups in 10 hips (Zimmer, Inc, Warsaw, IN), Trilogy cups in seven hips (Zimmer, Inc, Warsaw, IN), and one hip was revised using a Reflection acetabular component (Smith and Nephew Orthopaedics, Inc, Memphis, TN). Accompanying these components were 12 Longevity HXLPE liners (Zimmer, Inc, Warsaw, IN), five Trilogy (Zimmer, Inc, Warsaw, IN) liners, and one Reflection XLPE (Smith and Nephew Orthopaedics, Inc, Memphis, TN) liner.

Patients were followed as per routine with all THA patients. Patients were seen at 6 weeks following surgery, then again at 6 months, 1 year, 2 years, and 5 years. Anteroposterior and lateral radiographs were obtained at each visit, with the AP radiographs being standing radiographs unless contraindicated. Clinical examination including inspection of the surgical wound and range of motion of the hip were obtained at each visit. Clinical outcomes scoring sheets, including the Harris Hip Score [12] and UCLA [2], were filled out by the patient preoperatively and at all postoperative visits.

CT scans were performed an average of 60 months postoperatively (range, 12–121 months). All CT scans were performed at a single institution on a Sensation 16 scanner (Siemens Medical Solutions, Forchheim Germany). Subjects were placed in a supine position and their pelvis was scanned using a clinic protocol with parameters of 140 kVp, 450 mAs, 0.75 mm × 16 collimation, 1 second rotation, table feed 6 mm (pitch = 0.5), B50 kernel with extremity window, 400 to 450 mm field of view, and a 0.75 mm reconstruction interval. The CT image data for each subject were saved in the DICOM format and loaded into a standalone workstation for processing. The prerevision scans were performed using the available Siemens scanner at the time of the examination and ranged from 3 mm collimation to 0.7 isotropic voxels. For comparison of preoperative and postoperative scans all image data were resampled to 0.7 mm cubic voxels. Pre- and postoperative data were aligned in the same coordinate system using a

manual registration method available within the Analyze software (version 8.1, Biomedical Imaging Resource, Rochester, MN). The quality of the registration was visually checked using linked cursors in three orthogonal views. Prior to developing this study it was noted that the sclerotic border of the osteolytic lesion was not changed on postoperative CT scans. Thus, coregistering the pre- and postoperative CT scans allowed for assessing error in the quantification process. Also, because the sclerotic border remained, this allowed us to use postoperative CT scans to determine the region of original lysis and the amount of bone graft filling these lesions. In the subgroup of seven patients who had preoperative CT scans, there was no difference in the lesion volume ($p = 0.844$) or lesion surface area ($p = 0.166$) as described below when comparing the preoperative to postoperative CT examination. The mean percent difference for lesion volume was 5.7% and the mean percent difference for lesion surface area was 4.7%.

The CT scans of the 40 patients with osteolysis were randomized with respect to retained versus revised acetabular components and the lytic lesion volumes were measured by a single blinded observer (KES) with 16 years of medical CT image processing experience. We used the most commonly utilized criteria for defining osteolysis: a localized area of bone loss that is expansile, lacks osseous trabeculae, has a sharply demarcated sclerotic border, and has a clear communication to the joint space either adjacent to the acetabular component or surrounding a screw or screw hole [14, 15, 19, 26]. Lesions were segmented along sclerotic borders using a semi-automated edge strength based region growing technique in the axial, coronal and sagittal planes. In areas of high noise or low contrast manual tracing was used to complete or close the boundary. Segmentation and volume calculations were performed using Analyze software. The analysis was then reviewed in each plane by comparing the CT scans with and without volumetric fill to assess completeness of volume measurements. Three dimensional representations were created of each hip allowing further review of osteolytic lesions and the amount of graft fill. Once the areas of lysis were delineated, the percent of bone fill was determined by applying a threshold to the region of interest. Any voxel located within the region of interest with a threshold of 360 Hounsfield Units (HU) or above was labeled as 'bone fill' and any voxel with an intensity value below 360 HU was labeled as lysis. By sampling the intensity of regions of bone fill and areas of lysis it was determined that 360 HU was halfway between true value of the tissue and the true value of the surrounding tissue, which was found to minimize the effects of volume averaging. This value was visually assessed for its ability to separate bone fill from lysis by examining the gray scale image, the threshold

image, and a transparent overlay of the two. During the visual assessment it was noted that some streak artifact, due to metal, was above the 360 threshold level that would lead to an overassessment of bone fill. This error was on the order of 5%. Metal artifact was most severe through CT cuts involving the femoral head, and was most apparent in those with larger heads made of stainless steel. We therefore limited our evaluation to the supraacetabular area, which is the most clinically concerning area as this bears substantial amounts of weight.

The preoperative or immediate postoperative radiographs of those with lesions that fit the definition of osteolysis were then analyzed. Lesions that appeared to be osteolysis on the CT scan were excluded if there were cystic changes in the area of presumed osteolysis on preoperative or immediate postoperative radiographs. Radiographic assessment of fill and defect healing was performed using the AP images at the time of the CT scan. Blinded radiographs for each hip were copied to a disc. A second set of the same images were interspersed at random in order to assess intraobserver reliability. Three attending surgeons (RLB, JCC, RMN) with experience in reading radiographs with osteolytic lesions and bone grafts graded each set of radiographs. Reading of plain radiographs was performed blindly in that the examiners had no knowledge of the extent of defect fill or healing measured on CT. One of the authors not reading the radiographs (NAM) used a scatterplot of the percent fill on CT scan to develop the grading system, dividing the CT values into three roughly equal groups. Grade 0 fill was defined as less than 25% fill of the previous lytic defect ($n = 5$, averaged among graders), Grade 1 was defined as 26–50% fill of the previous lytic area ($n = 5$, averaged among graders), and Grade 2 was defined as greater than 50% fill of the lytic region seen on preoperative radiographs ($n = 30$, averaged among graders). Using percent fill on CT, there were nineteen grade 0, nine grade 1, and twelve grade 2. To assess defect healing we used the scoring system of Benson et al. [4]. Grade 1 was defined as some blurring of the lytic border but the border was still present or when a trabecular pattern had formed but was notably different from surrounding bone. Grade 2 was used when there was a loss of a distinct border between the area of lysis and surrounding bone, with a trabecular pattern to the bone and a density similar to that of surrounding bone. The correlation between the mean radiographic healing grade and the percent of contact with the host bone was then calculated. For the radiographic assessment, intraobserver and interobserver reliability were measured using a weighted kappa statistic for both defect fill and healing. Intraobserver reliability was moderate, with an average kappa statistic of 0.578 for graft fill and 0.583 for graft incorporation. Interobserver reliability for the amount of graft fill was

0.445, CI 0.32–0.57 and for graft healing 0.333, CI 0.22 to 0.44. Radiographic grading of graft fill correlated with ($\rho = 0.601$, $p < 0.001$) the grade based on the CT percent graft fill. The radiographic grade correlated with ($\rho = 0.278$, $p = 0.083$) the actual percent of surface area contacted by the bone graft (Table 2).

We assessed healing on CT using the amount of graft material in contact with host bone. A previous study demonstrated that only micro CT can detect true healing [9]; therefore, we elected to use the amount of graft in contact with host bone, which represents the maximum possible healing since the graft material must be in contact with host bone to potentially heal. Segmentation using the CT scans was used to assess this value in three dimensions. Blinded CT scans were then reviewed individually by two of the authors (RMN and NAM) to assess for the presence of bridging trabeculae.

A total of four patients in the study group required repeat revision surgery for osteolysis progression. Two patients had revision head and liner exchange with bone grafting and were included in the head and liner exchange group. The other two patients in the full acetabular revision group had previously failed head and liner exchange surgery. These patients experienced progression of their osteolysis with loosening of the acetabular component and were included in the acetabular revision group. There were no dislocations or revisions for dislocations in either group. The rate of reoperation in the head and liner group was four of 24 hips (17%). The average preoperative Harris Hip score was 71.3 (SD 16.9) in those with retained head and liner exchange only. Those with full acetabular revision had an average preoperative Harris Hip score of 57.0 (SD 16.4). Both the head and liner exchange group and the full revision groups had better Harris Hip scores at most recent followup ($p = 0.01$ and 0.0005 , respectively). The head and liner exchange group had a notably higher preoperative Harris Hip score ($p = 0.034$), but the Harris Hip score at the most recent followup was not statistically different between groups ($p = 0.618$) (Table 1).

When comparing preoperative and postoperative CT scans, the surface area percent differences were normally distributed and thus a paired t-test was used. Lysis volume, surface area, fill volume, contact area, percent fill, and

percent contact were not normally distributed and were compared with Wilcoxon signed-rank test. Spearman correlation coefficient was used to determine the correlation between radiographic grade and actual graft fill, as well as CT grade and graft contact.

Results

The average graft fill was 3.83 cm^3 (SD = 4.85 cm^3), which is only 31% of the total volume of osteolysis (mean 11.05 cm^3 (SD = 9.49 cm^3)). In the head and liner group, the average volume of graft material filling the osteolytic defect was 3.23 cm^3 (SD = 5.43 cm^3). This is 17% (range, 1%–52%) of the average lytic region. In the group with complete acetabular revision the average volume of graft material filling the osteolytic defect was 4.56 cm^3 (SD 4.06 cm^3), which filled 47% (range, < 1%–81%) of the lesion. Complete revisions had a higher percent ($p = 0.002$) defect fill compared to head/liner changes (47% versus 17%) (Table 1).

There was an average of 1.41 cm^2 (SD = 1.40 cm^2) of graft material in contact with the host bone. This represents only 24% of the total surface area of the osteolytic lesion (mean 5.57 cm^2 (SD = 3.00 cm^2)) that is contacting the graft substance, and likely healed. The average amount of graft material in contact with host bone was 1.06 cm^2 (SD = 1.35 cm^2) in the head and liner exchange group, which indicates only 14.4% (range 1% to 43%) of the surface area of the lesion was in contact with graft material. In the revised acetabular group 1.84 cm^2 (SD = 1.37 cm^2) of graft was contacting host bone, indicating 35.5 % (range, < 1%–66%) of the total surface area of the osteolysis was contacting graft material. Complete revisions had a higher degree ($p = 0.005$) of graft healing to host bone compared to head/liner changes (35.5% versus 14.4%) (Table 1).

There was a moderate correlation ($\rho = 0.601$, $p < 0.001$) between the radiographic grading of graft fill and the grade based on the CT percent graft fill [18]. There was also a moderate correlation between the radiographic grade and actual percentage of surface area contacted by the bone graft ($\rho = 0.278$, $p = 0.083$) [18]. The reliability of radiographs was quite variable; intrarater reliability ranged from a kappa of 0.26 to 0.77 for defect fill and from a kappa of 0.29 to 0.80 for graft incorporation. The kappa values for interrater reliability was 0.45 for graft fill and 0.33 for graft incorporation.

The total cost for the implants, excluding femoral stems, was \$4297 per case in the full acetabular revision group and \$1856 in the head and liner exchange group. Bone graft material costs averaged \$2586 per case in the head and liner exchange group and \$2179 in the full acetabular

Table 2. Radiographic analysis

Reliability	Graft fill		Graft healing	
	kappa	CI	kappa	CI
Intrarater 1	0.256	−0.05 to 0.57	0.293	0.03 to 0.56
Intrarater 2	0.773	0.59 to 0.95	0.797	0.64 to 0.95
Intrarater 3	0.706	0.49 to 0.92	0.658	0.32 to 0.57
Interrater	0.445	0.32 to 0.57	0.333	0.22 to 0.44

Table 3. Total amount and cost of graft material utilized

Graft material	Head and liner exchange				Full acetabular revision			
	Number of hips	Total number used	Contracted price (\$)	Total amount (\$)	Number of hips	Total number used	Contracted price (\$)	Total amount (\$)
Osteoset pellets	5	6	1085	6510	0	0	1085	0
Allograft croutons/cubes	8	13	565	7345	9	10	565	5650
Allograft chips	7	8	763	6104	7	12	763	9156
BMP	3	small - 2	3451	6902	0	0	3451	0
		large - 1	5408	5408	1	1	5408	5408
MIIG	3	25 cc - 2	3265	6530	0	0	3265	0
		15 cc - 1	2395	2395	0	0	2395	0
Allomatrix putty	7	5 cc - 2	920	1840	0	0	920	0
		5 + cc - 1	1195	1195	0	0	1195	0
		10 cc - 5	1420	7100	4	5	1420	7100
		10 + cc - 2	1730	3460	0	0	1730	0
Femoral head	1	1	850	850	8	14	850	11900
DBM	1	1	1242	1242	0	0	1242	0
Multiple types	13				10			
	Total amount (\$)		56881.00		Total amount (\$)		39214.00	
	Amount per patient (\$)		2585.50		Amount per patient (\$)		2178.56	

Osteoset Pellets. Wright Medical Technology, Inc. Arlington, TN.

MIIG = Minimally Invasive Injectable Graft. Wright Medical Technology, Inc. Arlington, TN.

Allomatrix Putty = Injectable Putty. Wright Medical Technology, Inc. Arlington, TN.

BMP = INFUSE bone morphogenic protein. Medtronic. Minneapolis, MN.

DBM = Demineralized bone matrix (multiple sources).

revision group (Table 3). Therefore, in the head/liner revision group, the cost of the graft material exceeded the cost of the orthopaedic implants.

Discussion

Osteolysis is a leading cause of revision THA and the optimal strategy for dealing with lytic lesions has not been well established. Lytic lesions are frequently grafted, but the outcome of these procedures is unknown. Our goals were to determine (1) the amount of the osteolytic defect that can be filled using two techniques: retaining a well-fixed acetabular component with exchange of the head and liner and bone grafting around or through the acetabular component and removing the acetabular component, bone grafting the defect and implanting a new component; (2) the amount of potential graft healing to host bone; and (3) the ability of plain radiographs to judge defect fill and healing was examined. We also wanted to determine (4) the cost of using bone graft substitutes in this setting and whether any difference existed between the two surgical types of procedures.

This study has notable limitations. First, ours was a retrospective study using multiple types of graft material,

implants, and grafting techniques depending on surgeon preference. Second, without sectioning the graft/host bone interface and microscopically assessing the trabeculae, there is no way to accurately assess bone healing. Micro CT replicates the images seen with microscopic examination; however, the radiation is much higher and not appropriate for human studies [9]. The next best option was to perform high resolution CT scans and determine the amount of host bone contacting graft material, which represents the greatest amount of healing possible since some of this may not have healed. Because of limitations with CT scans, soft tissue lysis was not measured in this study and the area of emphasis was localized to the superior acetabulum. However, greater amounts of lysis could have occurred and we did not measure the graft uptake in the greater trochanter or other grafted areas. Finally, a small percentage (10%) of the patients with revisions agreed to come back for CT examination, which can create a non-respondent bias; however, we attempted to contact everyone who met the inclusion criteria, giving all patients an equal opportunity to be involved in the study.

We demonstrated that only 16.7% of the osteolytic lesion volume in the weight bearing part of the acetabulum was filled with bone graft at an average 5.3 years following head and liner exchange revisions (Fig. 1). Also, only

Fig. 1 Sagittal CT reconstruction showing minimal defect fill or healing after grafting through a screw hole.

Fig. 2 CT section showing higher percentage defect fill but no contact between graft and host bone.

14.4% of the total surface area of the lesion had bone graft or new bone in contact with the margins of the lesion (Fig. 2). Therefore, despite vigorous irrigation and débridement of the lesions through and around the component, the amount of bone graft filling and healing in osteolytic lesions is quite small. This differs from previously reported filling capabilities [10, 25]. One of these studies measured immediate postoperative lesion filling on CT scan and demonstrated 49% lesion fill initially [10]. However, this

study had a larger average lesion size (20.3 ml) than our study (12.7 ml in the head and liner group), which could partially explain the difference in this study. Another study [25] demonstrated better graft incorporation and healing than we observed, with 54% of the average area being filled at an average 3.5 years followup. The lesions in that study were smaller in size than in our study, with an average of 6.38 cm²; however, the entire volume of the lesion was not measured and the total amount of fill could be inaccurate.

One study using radiographs to assess healing of bone graft and progression of lesions noted almost 100% incorporation of bone graft material with a major portion of the lesions no longer visible on radiographs [21], and greater than 90% survival at long term followup [32]. In the revised acetabular group, 47% graft fill was surprising since this procedure allows aggressive curetting and reaming of the lesion and complete visualization and probing of the acetabulum. Bone graft using reverse reaming appears to intraoperatively fill any remaining crevices or holes in the acetabulum, and reportedly leads to complete defect healing [11]. However, several recent studies have demonstrated plain radiographs are inferior to CT scans in determining both the incidence and size of osteolytic lesions [7, 19]. We found only a moderate correlation between radiographic grading and actual bone graft fill and healing. There were many subjects with radiographic appearance of healing with CT scans demonstrating substantial bony defects. Also, the reproducibility and interrater reliability between graders was suboptimal, which further demonstrates the inaccuracy of using radiographs for grading of lytic defects or success of bone grafting in the supraacetabular region.

Despite the low percentage of defect healing seen, there were few hips that needed subsequent surgery. The reported failure rate for revisions or dislocations in the literature is between 6% and 30% [5, 6, 24, 28, 36]. Four patients in the head and liner exchange group required subsequent surgery, two of whom underwent repeat head and liner exchange and two of whom underwent full acetabular revision. Perhaps the irrigation and débridement portion of the procedure halts or slows the osteolytic process. More likely, the replacement of the conventional polyethylene liner and damaged femoral head (the “debris generators”) with a lower wear, highly cross-linked liner and smooth femoral head component can prevent further progression of osteolysis and some degree of spontaneous healing. With an average of almost \$2500 spent on bone graft material that is not present at 5.3 years followup, the use of bone graft material may not be warranted. The three subjects in which BMP was used did have three of the highest fill and healing rates (Fig. 3). The role of BMP in augmenting graft healing of lytic defect is unclear at the present time but may warrant further study.

Fig. 3A–D Axial (A) and sagittal (B) views demonstrate cuts of a prerevision CT showing zone 1 lytic lesion. Grafting with allograft/BMP mixture through a cortical window resulted in a high percentage defect fill and healing, as seen on the axial (C) and sagittal (D) CT images.

Fig. 4A–D This figure demonstrates a complete acetabular revision associated with relatively high percent defect fill and healing. (A) The prerevision AP radiograph is shown. The AP radiograph taken at the time of CT scan (B) demonstrates near complete fill while the axial (C) and coronal (D) CT scan images demonstrate some graft resorption but relatively good fill.

We demonstrated retaining an acetabular component and attempting a bone graft either around or through the cup results in very little fill of the osteolytic defect and even less graft incorporation at 5.3 years followup. Revising the acetabular component greatly improves the amount of fill and is associated with a higher degree of defect healing (Fig. 4). In the case of head liner revisions, grafting the defect increases costs, especially considering the additional operative time. Given the surprisingly low percentage of defect fill and healing, the cost effectiveness of grafting around the periphery or through holes in a retained shell should be questioned.

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References

1. Beaman FD, Bancroft LW, Peterson JJ, Kransdorf MJ, Menke DM, DeOrto JK. Imaging characteristics of bone graft materials. *Radiographics*. 2006;26:373–388.
2. Beaulé PE, Dorey FJ, Hoke R, Leduff M, Amstutz HC. The value of patient activity level in the outcome of total hip arthroplasty. *J Arthroplasty*. 2006;21:547–552.
3. Beaulé PE, LeDuff MJ, Dorey FJ, Amstutz HC. Fate of cementless acetabular components retained during revision total hip arthroplasty. *J Bone Joint Surg Am*. 2003;85:2288–2293.

4. Benson ER, Christensen CP, Monesmith EA, Gomes SL, Bierbaum BE. Particulate bone grafting of osteolytic femoral lesions around stable cementless stems. *Clin Orthop Relat Res.* 2000;381:58–67.
5. Blom AW, Astle L, Loveridge J, Learmonth ID. Revision of an acetabular liner has a high risk of dislocation. *J Bone Joint Surg Br.* 2005;87:1636–1638.
6. Boucher HR, Lynch C, Young AM, Engh CA, Jr., Engh C, Sr. Dislocation after polyethylene liner exchange in total hip arthroplasty. *J Arthroplasty.* 2003;18:654–657.
7. Claus AM, Totterman SM, Sychterz CJ, Tamez-Pena JG, Looney RJ, Engh CA, Sr. Computed tomography to assess pelvic lysis after total hip replacement. *Clin Orthop Relat Res.* 2004;422:167–174.
8. Clohisy JC, Calvert G, Tull F, McDonald D, Maloney WJ. Reasons for revision hip surgery: a retrospective review. *Clin Orthop Relat Res.* 2004;429:188–192.
9. Cook SD, Patron LP, Salkeld SL, Smith KE, Whiting B, Barrack RL. Correlation of Computed Tomography with Histology in the Assessment of Periprosthetic Defect Healing. *Clin Orthop Relat Res.* 2009;476:3213–3220.
10. Engh CA, Jr., Egawa H, Beykirch SE, Hopper RH, Jr., Engh CA. The quality of osteolysis grafting with cementless acetabular component retention. *Clin Orthop Relat Res.* 2007;465:150–154.
11. Etienne G, Bezwada HP, Hungerford DS, Mont MA. The incorporation of morselized bone grafts in cementless acetabular revisions. *Clin Orthop Relat Res.* 2004;241–246.
12. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am.* 1969;51:737–755.
13. Howie DW, Neale SD, Stamenkov R, McGee MA, Taylor DJ, Findlay DM. Progression of acetabular periprosthetic osteolytic lesions measured with computed tomography. *J Bone Joint Surg Am.* 2007;89:1818–1825.
14. Kitamura N, Leung SB, Engh CA, Sr. Characteristics of pelvic osteolysis on computed tomography after total hip arthroplasty. *Clin Orthop Relat Res.* 2005;441:291–297.
15. Kitamura N, Naudie DD, Leung SB, Hopper RH, Jr., Engh CA, Sr. Diagnostic features of pelvic osteolysis on computed tomography: the importance of communication pathways. *J Bone Joint Surg Am.* 2005;87:1542–1550.
16. Kitamura N, Sychterz-Terefenko CJ, Engh CA, Sr. The temporal progression of pelvic osteolysis after uncemented total hip arthroplasty. *J Arthroplasty.* 2006;21:791–795.
17. Kontinen YT, Zhao D, Beklen A, Ma G, Takagi M, Kivela-Rajamaki M, Ashammakhi N, Santavirta S. The microenvironment around total hip replacement prostheses. *Clin Orthop Relat Res.* 2005;28–38.
18. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;33:159–174.
19. Leung S, Naudie D, Kitamura N, Walde T, Engh CA. Computed tomography in the assessment of periacetabular osteolysis. *J Bone Joint Surg Am.* 2005;87:592–597.
20. Lombardi AV, Jr., Berend KR. Isolated acetabular liner exchange. *J Am Acad Orthop Surg.* 2008;16:243–248.
21. Maloney WJ, Herzwurm P, Paprosky W, Rubash HE, Engh CA. Treatment of pelvic osteolysis associated with a stable acetabular component inserted without cement as part of a total hip replacement. *J Bone Joint Surg Am.* 1997;79:1628–1634.
22. Maloney WJ, Paprosky W, Engh CA, Rubash H. Surgical treatment of pelvic osteolysis. *Clin Orthop Relat Res.* 2001;393:78–84.
23. Maloney WJ, Wadey VM. Management of acetabular bone loss. *Instr Course Lect.* 2006;55:279–285.
24. O'Brien JJ, Burnett RS, McCalden RW, MacDonald SJ, Bourne RB, Rorabeck CH. Isolated liner exchange in revision total hip arthroplasty: clinical results using the direct lateral surgical approach. *J Arthroplasty.* 2004;19:414–423.
25. Puri L, Lapinski B, Wixson RL, Lynch J, Hendrix R, Stulberg SD. Computed tomographic follow-up evaluation of operative intervention for periacetabular lysis. *J Arthroplasty.* 2006;21:78–82.
26. Puri L, Wixson RL, Stern SH, Kohli J, Hendrix RW, Stulberg SD. Use of helical computed tomography for the assessment of acetabular osteolysis after total hip arthroplasty. *J Bone Joint Surg Am.* 2002;84:609–614.
27. Quinn SF, Murray W, Watkins T, Kloss J. CT for determining the results of treatment of fractures of the wrist. *AJR Am J Roentgenol.* 1987;149:109–111.
28. Restrepo C, Ghanem E, Houssock C, Austin M, Parvizi J, Hozack WJ. Isolated polyethylene exchange versus acetabular revision for polyethylene wear. *Clin Orthop Relat Res.* 2009;467:194–198.
29. Santavirta S, Hoikka V, Eskola A, Kontinen YT, Paavilainen T, Tallroth K. Aggressive granulomatous lesions in cementless total hip arthroplasty. *J Bone Joint Surg Br.* 1990;72:980–984.
30. Schmalzried TP, Fowble VA, Amstutz HC. The fate of pelvic osteolysis after reoperation. No recurrence with lesional treatment. *Clin Orthop Relat Res.* 1998;350:128–137.
31. Schmalzried TP, Jasty M, Harris WH. Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space. *J Bone Joint Surg Am.* 1992;74:849–863.
32. Schreurs BW, Slooff TJ, Gardeniers JW, Buma P. Acetabular reconstruction with bone impaction grafting and a cemented cup: 20 years' experience. *Clin Orthop Relat Res.* 2001;393:202–215.
33. Schwarz EM, Benz EB, Lu AP, Goater JJ, Mollano AV, Rosier RN, Puzas JE, Okeefe RJ. Quantitative small-animal surrogate to evaluate drug efficacy in preventing wear debris-induced osteolysis. *J Orthop Res.* 2000;18:849–855.
34. Sporer SM, Paprosky WG, O'Rourke MR. Managing bone loss in acetabular revision. *Instr Course Lect.* 2006;55:287–297.
35. Terefenko KM, Sychterz CJ, Orishimo K, Engh CA, Sr. Polyethylene liner exchange for excessive wear and osteolysis. *J Arthroplasty.* 2002;17:798–804.
36. Wade FA, Rapuri VR, Parvizi J, Hozack WJ. Isolated acetabular polyethylene exchange through the anterolateral approach. *J Arthroplasty.* 2004;19:498–500.