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Use of Helical Computed Tomography for the Assessment of Acetabular Osteolysis After Total Hip Arthroplasty

BY LALIT PURI, MD, RICHARD L. WIXSON, MD, STEVEN H. STERN, MD, JOE KOHLI, BA, RONALD W. HENDRIX, MD, AND S. DAVID STULBERG, MD

Investigation performed at the Departments of Orthopaedic Surgery and Radiology, Northwestern University Medical School, Chicago, Illinois

Background: Acetabular osteolysis is a major problem affecting long-term survival of total hip prostheses. Since lytic lesions may be asymptomatic until extensive bone loss has occurred, early detection of lytic lesions is important. The purposes of this study were to determine the efficacy and potential role of high-resolution helical (or spiral) computed tomography with metal-artifact minimization in the early detection of osteolysis of the pelvis and to use the method to determine if there was a relationship between the extent of osteolysis and the amount of polyethylene wear.

Methods: Forty patients (fifty hips) who had undergone primary cementless total hip arthroplasty between 1988 and 1994 were evaluated as part of an ongoing prospective study. These patients had a history of high-level activity that was believed to place them at increased risk for accelerated polyethylene wear. The most recent follow-up radiographs were compared with the three-month postoperative radiographs. Helical computed tomography scans with metal-artifact minimization were made, and evidence of osteolytic lesions on these scans was compared with that on the radiographs. Two-dimensional wear analysis was performed with use of digitized radiographs, and the results were compared with loss of bone volume as calculated from the computed tomography scans.

Results: Acetabular lysis was identified on the radiographs of sixteen hips and on the computed tomography scans of twenty-six hips. Radiographs underestimated the extent of the lysis in thirteen of the sixteen hips. There was no correlation (r = 0.036) between linear wear and the measured volume of bone loss, with the numbers available. On the basis of the amount of lysis seen on the computed tomography scans, one patient underwent a revision procedure.

Conclusions: Helical computed tomography with metal-artifact minimization is more sensitive for identifying and quantifying osteolysis after total hip arthroplasty than is plain radiography. Since computed tomography scans show both the extent and the location of lytic lesions, they are useful to guide treatment decisions as well as to assist in planning for surgical intervention, when needed, in patients with suspected osteolysis.

Periprosthetic osteolysis leading to component loosening has emerged as a major concern related to long-term implant survival after total hip arthroplasty[1-4]. Porous-coated acetabular implants with a modular polyethylene liner have been seen to have notable amounts of polyethylene wear. The consequence of this wear, osteolysis, can occur within the first few years after implantation and can be extensive. Patients often remain asymptomatic until extensive bone loss has occurred[5-9]. Acetabular implants may remain well fixed in spite of massive osteolysis. Such silent osteolysis has far-reaching clinical and economic implications[10]. Since the amount and location of pelvic lysis can determine the success of revision surgery[5,8,11], early detection of osteolysis in patients who have undergone total hip arthroplasty would be beneficial.

Radiographs provide limited information regarding the location and amount of osteolysis after total hip arthroplasty[12-15]. The ability to detect osteolysis on a radiograph can be affected by the patient's size, the position of the pelvis and extremity, the magnification of the radiograph, the radiographic technique, and the location of the lesion[16,17].

What is commonly referred to as a spiral technique, since the scan does not converge, is actually a helical scan. Helical computed tomography scanners obtain images in a continuous fashion as the table and patient move through the gantry. As a result, the scan time is shorter than that for conventional computed tomography, and there is less artifact due to movement. Since the computed tomography technique provides sequential images of lytic defects, the total volume of lytic bone loss can be determined.

The purpose of this study was to evaluate the efficacy and value of helical computed tomography used in conjunction with an artifact-minimization protocol to identify pelvic osteolytic lesions after total hip arthroplasty. The extent of osteolysis was then compared with the amount of polyethylene wear as determined with a computer-aided two-dimensional linear wear analysis.

Materials and Methods

In order to evaluate the efficacy of this computed tomography scan technique, we selected forty patients (fifty hips) with the diagnosis of osteoarthritis who had undergone primary total hip arthroplasty between 1988 and 1994. These patients were asymptomatic but were thought to be at increased risk for accelerated polyethylene wear because of their age, activity level, and size. All hips had an uncemented femoral component and an uncemented metal-backed acetabular implant with a modular polyethylene liner. A history was recorded for all patients, and all were evaluated with a physical examination, anteroposterior and lateral radiographs, and a helical computed tomography scan. A Harris hip score and the level of activity were determined for all patients at the time that the most recent radiograph was made. The mean Harris hip score was 92 points (range, 53 to 100 points). None of the patients had any hip pain. All patients examined with a helical computed tomography scan were included in this study. The clinical study of patients with total joint replacement at our institution, including this group of patients, was approved by our local institutional review board. With this approval, an informed consent procedure is not required.

Plain Radiographs

All follow-up radiographs were compared with the three-month postoperative radiographs by three senior surgeons (R.L.W., S.D.S., and S.H.S.) and a musculoskeletal radiologist (R.W.H.), all of whom were blind to the results of the computed tomography scans.

Pelvic osteolysis was defined as a new or expanding sharply demarcated lucency adjacent to the socket or screws. Preexisting cysts or relative areas of osteopenia were not considered to represent osteolysis. There had to be a change compared with the three-month radiograph for a diagnosis of osteolysis to be made. The size of each lesion was determined by measuring its longest diameter and a second diameter perpendicular to the first. The location of each lesion was then classified according to the zones of DeLee and Charnley[18]. The lesions were also characterized as expansile or linear, and as cavitary or segmental[19].

All acetabular components were evaluated for signs of loosening, which was defined as migration as assessed with the method of Massin et al.[20]. In addition, a loose component was defined as one with a radiolucent line of >1 mm in all three zones that was seen to have progressed on serial radiographs[13], or as a cup with loose beads.

Helical Computed Tomography

All hips were evaluated with helical computed tomography near the time of the last clinical and radiographic follow-up. The mean time-interval between the surgery and the computed tomography was 7.6 years (range, 3.0 to 13.6 years). The hips were scanned from 6 cm proximal to the acetabular component to a point distal to the end of the implant. A metal-artifact-minimizing protocol was used. This consisted of scanning at 140 keV, no image enhancement, a pitch of ≤1.0, as small a field of view as possible, a bone algorithm, and overlapping of images by ≥50%. The computed tomography scans were made with an Elscint CT Twin (Picker International, Cleveland, Ohio) or a GE Light Speed (General Electric, Milwaukee, Wisconsin) helical scanner. Patients were scanned in the axial plane, and coronal and sagittal images were generated from the axial images. The maximum thickness of the cuts ranged from 2.7 to 3.1 mm.

All scans were reviewed independently by the surgeons and radiologist. If there was disagreement among the interpretations, a consensus opinion was achieved. Pelvic osteolysis was defined as any sharply demarcated area adjacent to the socket or screws without osseous trabeculae (Fig. 1). The largest diameter of the lesion was measured. The lesions were described as being located in the ilium, acetabular roof, medial wall, anterior column, posterior column, ischium, or pubic ramus. The lesions were also evaluated for proximity to a screw or a screw-hole. In addition, the lesions were characterized as cavitary or segmental.

Lytic Volume

Lesions were identified and traced on each axial cut with use of a semiautomated edge detection module (Adobe Photo-

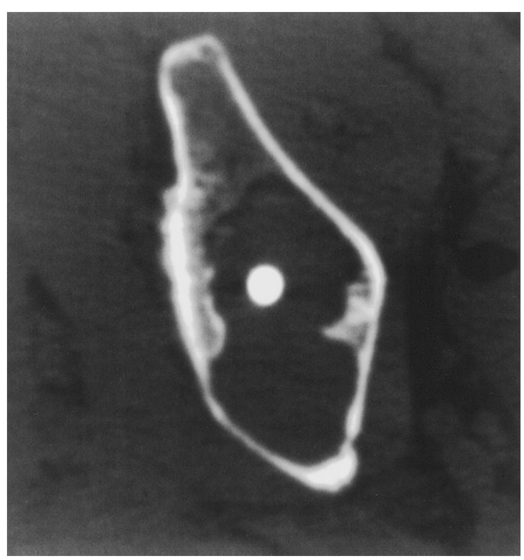

Fig. 1
Example of a lytic lesion, with sharply demarcated edges and without osseous trabeculae, seen on an axial computed tomography image.

TABLE I Size of Lytic Defects and Linear Wear

Lytic Defects	No. of Hips	Maximum Diameter of Lesion on Radiograph* *(cm)*	Volumetric Bone Loss on Computed Tomography Scan* *(cm³)*	Linear Wear* *(mm)*
None	24	—	—	0.9 ± 0.6
Seen on computed tomography scan only	10	—	2.8 ± 2.8	0.8 ± 0.5
Seen on radiographs and computed tomography scan	16	1.7 + 1.1	6.8 ± 8.5	1.5 ± 1.0

*The values are given as the mean and the standard deviation.

shop 4.0, San Jose, California) according to the method described by Whang et al.[21] (Fig. 2). The areas of the lytic lesions were then calculated from each tracing by determining the number of pixels per square centimeter. The volume between adjacent cuts was calculated by averaging the areas between adjacent cuts multiplied by the distance between cuts. Summation of the volumes on each of these cuts was used to determine the total volume of bone loss due to lysis.

Wear Analysis

Plain anteroposterior radiographs of the pelvis, made at six weeks after the operation and at the latest follow-up examination, were digitized at 150 dpi resolution. With use of a computer software program described by Martell and Berdia[22], two-dimensional paired analyses of linear wear and wear vector were performed. This program uses edge-detection techniques to define the outlines of the metal acetabular shell and the femoral head with derivation of their centers. The distances and directions between these center points provide the linear wear and vector values. The displacement over time is a measure of both the wear and the amount of creep of the polyethylene.

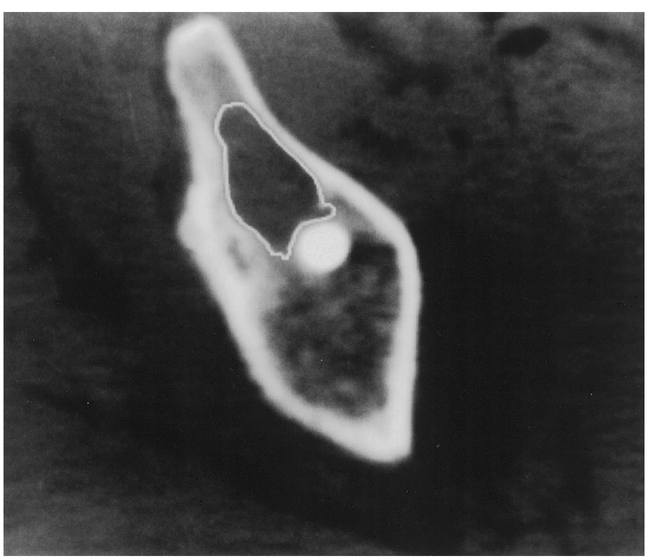

Fig. 2

Axial computed tomography image of a lytic area with tracing of the edges.

Statistical Analysis

The significance of differences in measured values between groups was assessed with the independent samples Student t test with use of SPSS software program (version 9.0; SPSS, Chicago, Illinois) and the Pearson product-moment correlation coefficient r.

Results

None of the fifty hips demonstrated radiographic evidence of loosening or migration. Twenty-four hips had no evidence of pelvic osteolysis on the plain radiographs or the helical computed tomography scan. The other twenty-six hips had evidence of pelvic osteolysis on the computed tomography scans; sixteen of them had evidence on plain radiographs as well and the remaining ten had no evidence on plain radiographs. On the basis of these data, the sensitivity of radiographs for identifying lysis was 62% and the specificity was 100%.

The average Harris hip score for the sixteen hips with osteolysis detected on both the radiographs and the computed tomography scan was 92 points (range, 66 to 100 points). The computed tomography scans of these hips were made at an average of 7.6 years (range, 4.4 to 13.4 years) after surgery. In three of the sixteen hips, the amount and location of the lysis seen on radiographs were similar to the amount and location seen on the computed tomography scan (see Appendix). In all three hips, the greatest diameter of the lesion measured on the radiographs was within 5 mm of the greatest diameter measured on the computed tomography scan. The radiographs of the remaining thirteen hips led to an underestimation of the amount and/or locations of the osteolysis compared with the measurements on the computed tomography scan (Figs. 3-A and 3-B). One patient in this group underwent a revision procedure on the basis of the extent of the lesion revealed by the computed tomography scan. Before this intervention, six years after the index procedure, this patient had a Harris hip score of 93 points. All lesions were expansile and cavitary. Of the sixteen hips in this group, twelve had a lesion adjacent to or surrounding a screw or screw-hole.

The average Harris hip score for the ten patients with negative radiographs and a positive computed tomography scan was 97 points (range, 86 to 100 points). The computed tomography scans were made at an average of 6.7 years (range, 3.2 to 10.2 years) after surgery. The greatest dimension of the

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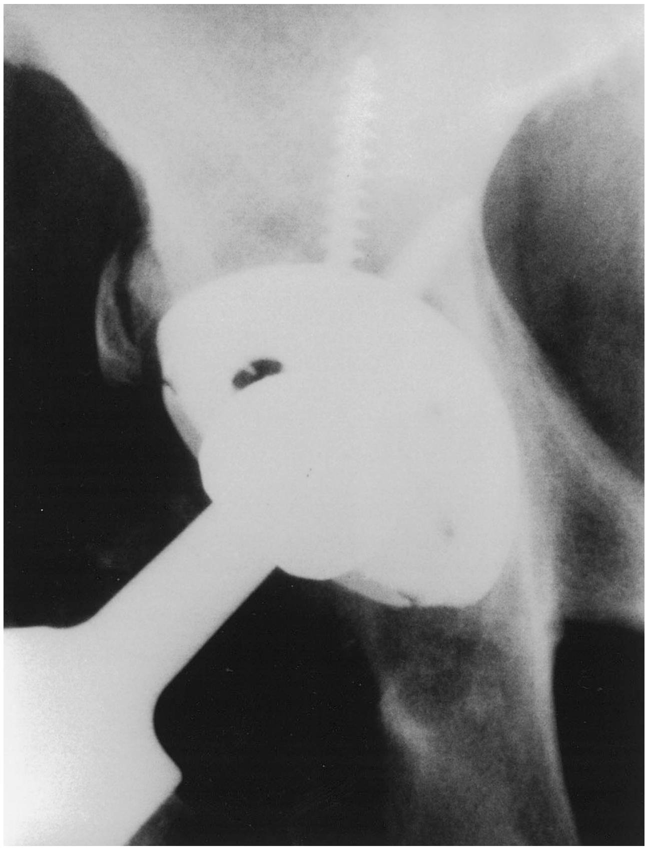


Fig. 3-A
Anteroposterior radiograph of an asymptomatic seventy-year-old man, made seven years postoperatively, showing minimal evidence of osteolysis.

lesions ranged from 6 to 38 mm (mean, 16 mm). Nine hips had a lesion adjacent to or surrounding a screw or screw-hole (see Appendix).

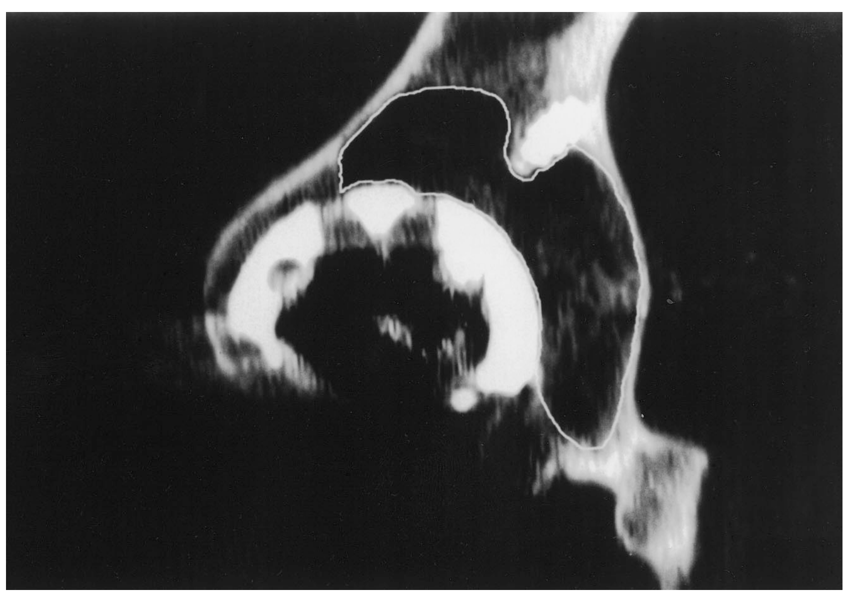
Two-dimensional linear wear varied among the different groups. Patients with either no evidence of lysis or evidence only on the computed tomography scan had the least amount of wear (0.9 and 0.8 mm, respectively) (Table I). With the numbers available, there was no significant difference between those two groups. Patients with lysis detected on both radiographs and the computed tomography scan had the greatest amount of wear (1.5 mm, which corresponds to 580 mm^3 of wear for a 28-mm head diameter). This value was significantly different from the wear in the other two groups ($p = 0.022$). The mean maximum diameter (and standard deviation) of the lesions that were seen on both the radiographs and the computed tomography scan was 27 ± 14 mm compared with 16 ± 11 mm for the lesions seen on the computed tomography scan only. With the small numbers and large standard deviation, this mean difference of 11 mm was not significant ($p = 0.051$).

The volume of bone loss due to lysis was calculated for twenty-five of the twenty-six hips with lysis detected on the computed tomography scan. The mean volumetric bone loss was 4.9 cm^3 (range, 0.3 to 35.1 cm^3). One hip had a lytic lesion measuring 35.1 cm^3, and the bone loss in the other twenty-four hips ranged from 0.3 to 10.8 cm^3. The amount of volumetric bone loss did not correspond with radiographic evidence of lysis. Furthermore, there was no correlation between volumetric bone loss and linear wear of the polyethylene ($r = 0.036$), with the numbers available.

Discussion

Polyethylene wear causing osteolysis and subsequent loosening continues to threaten long-term survival of total hip replacements[3]. Although investigators have identified factors that influence the rate and amount of wear of total hip replacements over time, the process still continues at an undesirably high rate[1,23,24].

Fig. 3-B
Sagittal computed tomography reconstruction showing the portion of the lesion behind the acetabular cup that is not apparent on the standard anteroposterior radiograph.



Classification systems with algorithms for the treatment of osteolysis have been developed[19,25-29]. However, these algorithms depend heavily on the identification of the amount, location, and nature of the osteolysis. Currently, the extent of pelvic osteolysis is established on the basis of the patient's interval history, physical examination, and serial radiographs. Alternate methods, such as computed tomography, for evaluating bone adjacent to metal implants have been sought. Initially, these methods were found to be of limited value[30,31]. However, the use of metal-artifact-suppression protocols has generated renewed interest in the use of computed tomography scans for assessment of bone adjacent to metal joint implants[32-34].

The concept of "silent osteolysis" was introduced by Lavernia et al.[7] to call attention to patients who had radiographically identifiable osteolysis in the absence of symptoms. This principle may now apply to patients who have neither symptoms nor evidence of osteolysis on radiographs but have evidence of osteolysis on computed tomography scans. The early recognition of osteolysis may increase the likelihood of successful medical or surgical intervention[5,10,11,26].

The goal of this study was to assess whether helical computed tomography is useful for the evaluation of osteolysis, not to determine the prevalence of osteolysis in patients who have undergone total hip arthroplasty. The patients included in the evaluation were specifically selected because they were thought to be at increased risk for accelerated polyethylene wear as a consequence of their age, level of activity, or size. In this group of patients, the computed tomography scan provided more accurate information about the presence, location, and extent of osteolysis than did standard radiographs. Of the twenty-six patients who were found to have osteolysis on the helical computed tomography examination, ten had no radiographic evidence of osteolysis and sixteen had such radiographic evidence. In thirteen of the sixteen patients with a radiographically evident lesion, the extent of the osteolysis was underestimated on the radiographs. Thus, 88% (twenty-three) of the twenty-six patients who had evidence of osteolysis on the computed tomography scan had inaccurate radiographs.

This study confirms previous observations that polyethylene wear does not necessarily result in radiographic evidence of lysis[2,35-38]. Patients had polyethylene wear even without evidence of lysis on the more sensitive computed tomography scan. However, the amount of wear was greatest when lysis was seen on both standard radiographs and the computed tomography scan.

An important observation is that the quantitative volume of bone loss due to lysis did not correlate with linear wear ($r = 0.036$). This finding suggests that lysis is not entirely dependent on particulate debris load and may be due to other factors.

On the basis of the results of this initial study, the current indication for computed tomography at our institution is an increased risk for lysis after five years as a consequence of young age, level of activity, patient size, substantial wear on follow-up radiographs, radiographic evidence of lysis, or an acetabular component known to be associated with accelerated polyethylene wear. Computed tomography is also used extensively as part of preoperative planning prior to surgical intervention. We suggest that, in current and future clinical trials of the recently introduced highly cross-linked polyethylenes, metal-on-metal articulations, and ceramic-on-ceramic articulations, hips be evaluated with use of serial computed tomography scans as a method for detecting early wear behavior of these new devices.

Limitations of this study include sample size, selection criteria, and the use of two-dimensional wear calculations. In this study, we did not have the capability to compare the size of the bone lesions seen on computed tomography scans with that of lesions seen at surgery or in retrieved specimens. We selected patients believed to be at high risk for osteolysis in order to determine the ability of this method to detect and quantify osteolysis. Additional studies of unselected patients will be required to determine the true prevalence and extent of the condition. The two-dimensional wear calculations were based on digitized anteroposterior radiographs because we do not routinely make the cross-table lateral radiographs required for three-dimensional wear analysis. Martell et al. demonstrated that results of the two-dimensional technique correlate closely with those of the three-dimensional analysis[39].

In conclusion, this study indicates that radiographs underestimate the extent of osteolysis and that the helical computed tomography with metal-artifact minimization is a sensitive and accurate method for assessing the presence and extent of pelvic osteolysis. ■

Appendix

eA A table showing the size, extent, and location of lytic lesions on the radiographs and helical computed tomography scans is available with the electronic versions of this article, on our web site at www.jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM).

Lalit Puri, MD
1800 Lombard Street, Suite 801, Philadelphia, PA 19146

Richard L. Wixson, MD
Steven H. Stern, MD
Northwestern Center for Orthopedics, 676 North St. Clair Street, Suite 450, Chicago, IL 60611

Joe Kohli, BA
Department of Orthopaedic Surgery, Northwestern University Medical School, 645 North Michigan Avenue, Suite 1058B, Chicago, IL 60611

Ronald W. Hendrix, MD
Department of Radiology, Northwestern University Medical School, 676 North St. Clair Street, Suite 800 Chicago, IL 60611

S. David Stulberg, MD
Northwestern Orthopaedic Institute, 680 North Lake Shore Drive, Suite 1028, Chicago, IL 60611

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