Quantitative Analysis of Technetium-99m-Methylene Diphosphonate Uptake in Unilateral Hydroxyapatite-Coated Total Hip Prostheses: First Year of Follow-Up

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A prospective study was performed on 80 patients who had undergone a unilateral hydroxyapatite (HA)-coated total hip arthroplasty to establish the normal periprosthetic uptake of methylenediphosphonate (MDP) as a function of implant age. **Methods:** Patients were imaged periodically while they were asymptomatic at 1, 3, 6 and 12 mo postoperatively. Quantitative measurements were performed with a region of interest (ROI) technique. The HA-coated and uncoated areas were marked in comparison with the normal contralateral femur. The uptake ratios of the MDP were determined postoperatively in the following 12 mo. **Results:** It was found that a decrease of the uptake ratios occurred in all ROIs. However, for the HA-coated areas, the uptake ratios still remained raised as a result of bony ingrowth. **Conclusion:** The results of the first year of follow-up were considered to be a normal database that will be used as a reference when the same group of patients are followed up to 5 yr postoperatively to detect any potential modes of failure of the implant.

Key Words: hydroxyapatite; total hip arthroplasty; radionuclide

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Total hip replacement is now well established as a method to relieve pain and restore mobility in the dysfunctional joint. The most widely used material for the replacement of hip joints is a femoral component, which consists of a small metal sphere attached to a stem inserted into the medullary canal of the femur, in combination with an acetabular component, which consists of a cup made from an ultrahigh molecular weight polyethylene. These components are fixed to the skeleton by one of two methods: the use of acrylic as bone cement or by bony ingrowth. Notwithstanding the excellent and good results in approximately 95% of the patients who undergo cemented total hip arthroplasties (THAs) (*1*), the drawbacks of cement are well known (*2*). Over time, the failure of the cemented components to remain fixed to the skeleton has become an increasingly frequent and serious adverse event. Efforts to improve the fixation of the components (*3*) to increase the durability of THA have led to several new developments, such as: (1) improvements in stem geometry (left and right stem) to achieve a closer fit between the implant and bone, (2) porous coating of the implant surface to increase the area of contact and (3) coating of the implant with hydroxyapatite (HA), which has been shown to stimulate bone formation and osseointegration.

The HA-coated prosthesis relies on bone ingrowth for fixation and stability of the implant components. Therefore, an increased uptake of bone-avid isotopes may be recorded, especially around the HA-coated part of the prosthesis. This study attempted to establish the normal course and duration of bony ingrowth with the HA-coated type of prosthesis. Eighty asymptomatic patients were prospectively studied. A quantitative assessment of the methylenediphosphonate (MDP) uptakes was associated with the HA-coated prosthesis. The results are presented here from the first year of follow-up.

METHODS

Patients and Materials

Between June 1990 and July 1992, 145 primary noncemented HA-coated THAs were implanted in 127 patients. The prosthesis used was registered as the Anatomic Benoist Girard (ABG) implant (Howmedica International, Rutherford, NJ). The hemispheric metal-backed cup was covered with HA as was the proximal part of the stem (Fig. 1). There was a left and right stem. To get a completely tight fit of the proximal HA-coated part of the stem, the diaphysis of the femur was reamed. All patients gave informed consent to participate in the study, which was approved by the Medical Ethics Committee of the hospital.

Eighteen patients had bilateral THAs and were excluded from the study. One patient died, and 28 others did not fulfill the protocol criteria because of inadequate attendance for follow-up investigations. The study group included 80 asymptomatic patients (59 women and 21 men) with unilaterally implanted HA-coated ABG prostheses. The patients' ages varied from 23 to 89 yr (mean 64.3 yr). The radionuclide studies were scheduled at 1, 3, 6 and 12

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FIGURE 1. Quantitative bone scintigraphy of cementless HA-coated ABG hip prosthesis.

mo postoperatively and will be repeated at 2, 3 and 5 yr. All patients had experienced a pain-free, fast functional recovery. The serial clinical evaluation with the Merle d'Aubigné score for function at 1 yr postoperatively was excellent in 78 patients and good in 2. All patients demonstrated radiographic evidence of osseointegration of the stem and the cup.

Imaging Technique

All patients received an intravenous injection of 555 MBq (15 mCi) of ^{99m}Tc-labeled MDP. Patients were instructed to drink as much water as possible during the waiting period and to void before scanning. After approximately 3 hr, 350,000 counts were obtained from the upper posterior thoracic vertebral region with a Siemens large-field-of-view gamma camera with an all-purpose collimator (Siemens Gamma Sonic, Hoffman Estates, IL). The time of this static image was noted and used as a preset time for the rest of the images. Anterior, posterior and lateral images of the hip implant were obtained and stored in the 128 × 128 matrix of a modern data-processing system (ADAC, Milpitas, CA) for subsequent analysis. The patient was positioned in the same manner for each examination so that comparable scintigrams were obtained.

Quantitative Analysis of Single Images

The anterior projection of the pelvis was used to mark the regions of interest (ROIs, Fig. 2). Four ROIs were marked over the prosthesis. ROI I was marked over the HA-coated acetabular component and ROI II was marked over the area between the acetabular component and the intertrochanteric zone. It included both the lesser and the greater trochanters and ectopic bone-forming areas. ROI III was marked over the HA-coated part of the femoral stem, which was located at the upper third of the stem. ROI IV was marked over the remaining part of the stem and included the tip. The fifth ROI was marked over the contralateral normal femur and corresponded to the level of ROI IV. It was used as a reference. The ROIs drawn in the first study month were saved in each patient's file and were recalled and applied to the next sequential study at 3, 6 and 12 mo. They will also be used at 2, 3 and 5 yr postoperatively. The counts per pixel were obtained, and the average (mean value) counts per pixel for each ROI was calculated. The uptake ratios were expressed as the mean value of each ROI with respect to the mean value of the reference ROI.

The significance of the differences was assessed by Student's t-test (level of significance $p = 0.05$).

RESULTS

The results are detailed in Tables 1 and 2. As expected, the means of all ROIs were significantly low at 12 mo postoperatively. However, the change of regression (trend) was different in the HA-coated ROIs in comparison to the uncoated ones. At 12 mo, the HA-coated ROIs I and III still had 60.6% and 57.1% of their baseline activities, whereas in contrast, the uncoated ROIs II and IV showed 45.7% and 43.3%.

ROI II showed the highest mean of all ROIs at 1 mo. The scintigraphic findings of this region showed a "hot" greater trochanter in 80 patients (100%) and a hot lesser trochanter in 25 patients (31%).

In 55 patients (69%), evidence of ectopic bone formation with different degrees of intense activity was seen on the 1-mo scan, at least in two projections. The mean in this group of patients was 4.60 ± 1.34 and it declined to 1.89 ± 0.40 after 12 mo. In the same period, 25 patients (31%) who had no ectopic bone formation yielded a mean of 2.45 ± 0.32, which declined to 1.29 ± 0.29 after 12 mo.

ROI IV showed the lowest mean of all ROIs at 12 mo and never exceeded a score of 1.8. The mean of this region declined rapidly from 3.0 ± 0.84 (at 1 mo) to 1.4 ± 0.24 (at 12 mo).

DISCUSSION

The cementless HA-coated hip prosthesis demonstrates a bone reaction that is different from that of the cemented one. Indeed, this new HA-coated prosthesis (ABG) creates a new biomechanical relationship. By the surgeon reaming the femur to accommodate the distal part of the stem, biomechanical stress transfer should be attained exclusively proximally. The radiologic follow-up in this group of patients has demonstrated a rapid bony integration of implants with bone apposition on the coating. These results correlate well with other reports in the literature (*4*). Scintigraphically, these HA-coated ROIs I and III have shown only a slow decline of their means as a function of time.

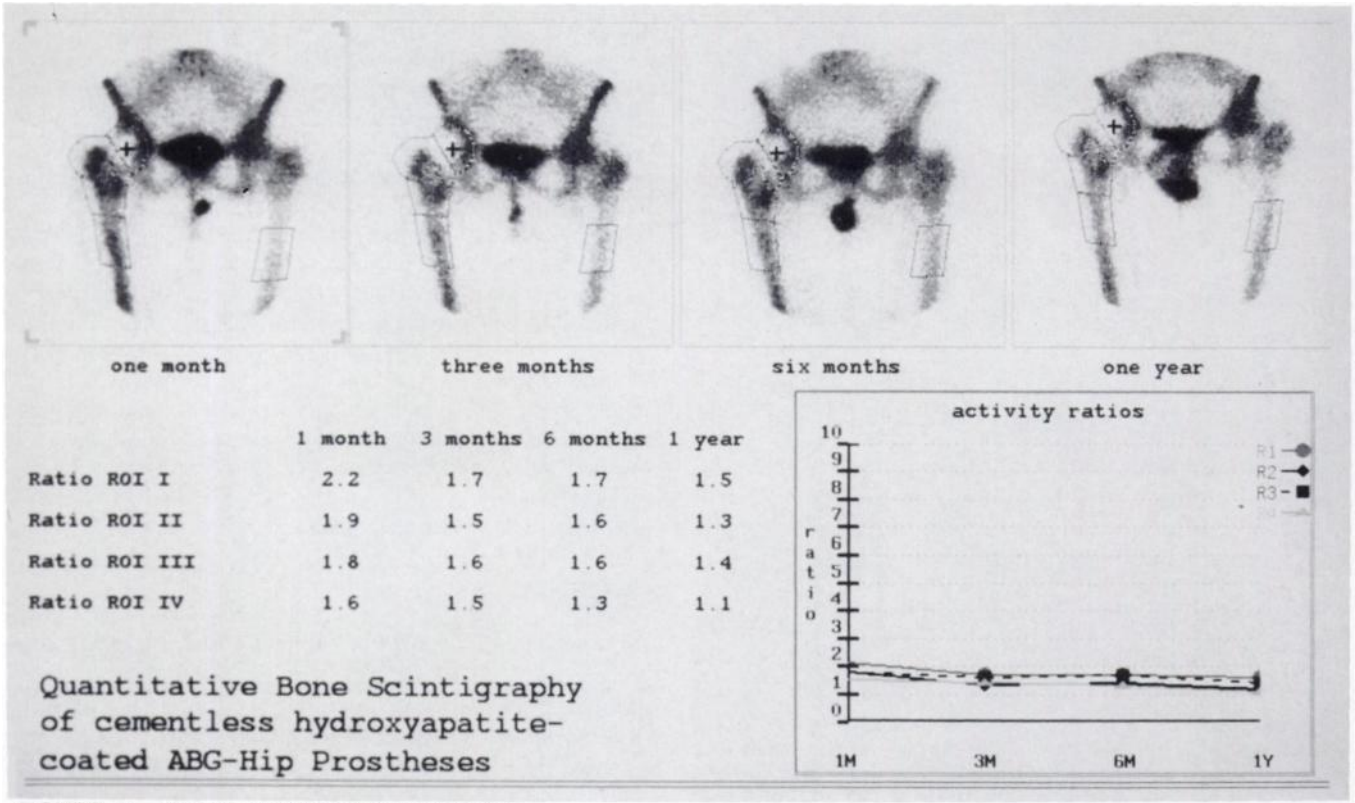

FIGURE 2. Photograph of the original prosthesis.

After 12 mo, they still remain the most active ROIs. These results suggest that ingrowth of bone occurs mainly at the HA-coated ROIs I and III.

Histologic findings (*5,6*) in postmortem specimens of HA-coated prostheses have shown early deposition and bridging of new woven bone between the HA-coated implant and the femur. This woven bone differs histologically from normal lamellar bone (*7*) and has a much larger surface area. It is lined with metabolically active osteoblasts. In addition, the crystalline structures in woven bone are smaller and have a larger surface area available for absorption of bone-seeking radiopharmaceuticals. In the present study, new woven bone bridged the gap between the endosteal surface and the HA-coated portion of the implant (ROIs I and III), which correlated well with the persistent high concentration of MDP at these sites after 12 mo. This almost certainly reflects ongoing active bone remodeling. With respect to ROI II, the high uptake ratio seen at 1 mo was mainly related to the operative trauma. In this patient group, only partial resection of the greater trochanter was performed to accommodate the prosthesis, and hyperperfusion and reactive osteoblastic activity were common findings. Ectopic ossification is a frequent complication with varying degrees of intensity (*8*). It can be detected scintigraphically as early as 1 mo (*9,10*). In total, 69% of the patients studied showed early ectopic ossifications, which decreased to 28% at 12 mo. Patients with ectopic ossification had much higher uptakes than those without.

This investigation showed that uptake ratios around the stem tip revealed the lowest osteoblastic activity and were

TABLE 1
Uptake Ratios of the Hydroxyapatite-Coated Anatomic Benoist Girard Prosthesis

ROI	Mean uptake ratio value ± s.d.*			
	After 1 mo	After 3 mo	After 6 mo	After 12 mo
I	3.4 ± 0.96	2.8 ± 0.81	2.4 ± 0.62	2.0 ± 0.60
II	3.9 ± 1.52	2.9 ± 1.21	2.2 ± 0.73	1.7 ± 0.46
III	3.0 ± 0.86	2.2 ± 0.51	1.9 ± 0.43	1.6 ± 0.40
IV	3.0 ± 0.84	2.1 ± 0.53	1.7 ± 0.40	1.4 ± 0.24

*Mean values (1 s.d.) of the various ROIs (I to IV) at four measuring time points. All means within each ROI were significantly different ($p < 0.001$, by Student's t-test).

TABLE 2
Decrease of the Uptake Ratios of the Anatomic Benoist Girard Prosthesis*

ROI	After 1 mo Baseline value (%)	After 3 mo Baseline value (%)	After 6 mo Baseline value (%)	After 12 mo Baseline value (%)
I	100	81.8	66.7	60.6
II	100	77.1	57.1	45.7
III	100	75.0	64.3	57.1
IV	100	66.7	53.3	43.3

*Trend of the decrease of the uptake ratios of the prosthesis up to 12 mo.

The p values by the Mann-Whitney U test are ROI I vs. ROI II, $p < 0.0001$; ROI I vs. ROI IV, $p < 0.0001$; ROI II vs. ROI III, $p < 0.0001$; ROI III vs. ROI IV, $p < 0.0001$.

the first to achieve normalization. Biomechanically, this means that, at this part of the prosthesis, there is hardly any stress transfer.

Few methods to quantify bone uptake in cementless THAs based on computer-assisted measurements have been reported (*11–15*). Rosenthall et al. (*12*) reported on the normal temporal concentrations of MDP with two different designs of cementless porous-coated prostheses. They found different uptake ratios with the S-ROM (Joint Medical Products Corp., Stanford, CT) design prosthesis compared with the AML type. The mechanism of bone ingrowth fixation in the ABG prosthesis is different from that in the porous-coated prosthesis (*4*). Also, a lower uptake ratio was found at ROI IV (1.4) with the ABG prosthesis than the tip-to-stem ratio (1.6) with the AML prosthesis (*12*). The authors agree with Rosenthall et al. (*12*) that it is probably going to be necessary to determine the normal temporal MDP changes for each different design of prosthesis.

In conclusion, based on 12 mo of prospective study, the normal temporal uptake ratios of the ABG type of prosthesis were established. These ratios are the normal database that will be used as a reference when there is a clinical suspicion of a complication. The mean scores for the HA-coated ROIs I and III were 2.0 ± 0.6 and 1.6 ± 0.4 and those for the uncoated ROIs II and IV were 1.7 ± 0.46 and 1.4 ± 0.24. The osseointegration occurred mainly in the HA-coated part of the ABG prosthesis, although the osteoblastic activity in these parts decreased, but it still remained above normal levels as a result of ongoing bony ingrowth. A delayed increase in the uptake ratio may be a sign of nonintegration of the prosthesis or of a loosening process, but the method's efficacy to disclose implant complications is yet to be determined.

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