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Postmortem Analysis of Bone Growth into Porous-Coated Acetabular Components[*]

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ABSTRACT: **Microradiography, backscattered electron microscopy, and histological analysis were used to conduct a quantitative postmortem study of seven consecutively retrieved anatomical porous replacement acetabular components that had been inserted during total hip arthroplasties. Screws had been used for the initial fixation of six components. The microradiographic analysis of all seven components showed that an average (and standard deviation) of 84 ± 9 per cent (range, 72 to 93 per cent) of the porous coating was in direct apposition to the periprosthetic bone. The backscattered electron images demonstrated that an average of 12 ± 6 per cent (range, 4 to 21 per cent) of the space available in the porous coating was occupied by ingrown bone. The amount of bone ingrowth was not significantly different among the three zones delineated by DeLee and Charnley. Uniformity of bone growth into the porous coating suggests that the preferential loading that occurs in the superior region did not differentially affect the bone ingrowth. The present study showed that consistent bone growth into anatomical porous replacement acetabular components can be achieved.**

In a previous study[27], it was concluded that porous-coated acetabular components may not be as clinically durable as components inserted with cement. Additional investigation has suggested that bone ingrowth over large surface areas of porous-coated implants is difficult to achieve[10,15]. Two reasons that have been cited for the lack of consistent bone ingrowth are initial instability of the implant and gaps between the implant and the host bone[3,17,20,23,32]. Some authors have reported that the use of screws improves initial fit and stability[19,24], helps to reduce micromotion[10,33], and therefore contributes to increased bone ingrowth compared with that found in components implanted without screws. However, Peters et al.[23] reported that screws are associated with migration of particulate debris along the screw tracks into the periprosthetic tissue, leading to large regions of osteolysis. The benefit of screws as an adjunctive method of initial fixation is still in question.

The purpose of the present investigation was to determine quantitatively the response of bone in a series of clinically successful porous-coated acetabular components retrieved postmortem from previously active patients. Three hypotheses were tested. The first hypothesis was that there would be more bone ingrowth in the superior region than in the medial and inferior regions because of preferential loading — that is, that increased formation of bone at this location would lead to increased bone ingrowth compared with that in the other regions. This hypothesis was based on observations of the wear patterns in the superior portion of the acetabular inserts as well as on studies concerning the trajectorial theory of Wolff[34]. That theory states that there is increased formation of bone and cancellous bone orientation along the strain trajectory in areas in which the loads are higher than the loads in other regions. Skedros et al.[30,31] and others[9,22] have confirmed that differences in regional loading cause differences in the amount of bone mineral and in the morphology of the bone.

The second hypothesis was that the amount of bone growth into the porous coating would be equal to the amount of periprosthetic bone in the region directly adjacent to the porous coating. Bone ingrowth was measured as a per cent volume fraction of the bone present in the total available pore space, and the periprosthetic bone was measured, with identical measurement parameters, as the per cent volume fraction of the bone directly adjacent to the porous coating. This hypothesis was based on the assumption that cancellous bone may be genetically limited to form a given volume of bone, thereby maintaining a volume of bone ingrowth equal

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TABLE I

CLINICAL DATA OBTAINED FROM THE PATIENTS' RECORDS

Case	Side	Gender	Reason for Arthroplasty	Time Implant *in Situ* *(Mos.)*	Last Harris Hip Score[16] *(Points)*	Age at Death *(Yrs.)*	Cause of Death
1	R	M	Osteoarthrosis	10	94	68	Prostate carcinoma
2	R	F	Osteoarthrosis	36	85	52	Pulmonary carcinoma
3	R	F	Rheumatoid arthritis	19	65	35	Heart attack
	L			27	65		
4	R	M	Osteoarthrosis	64	100	71	Stroke
	L			64	100		
5	L	M	Osteoarthrosis	48	100	58	Stroke
Average and standard deviation				38 ± 21		57 ± 14	

to or less than the volume of periprosthetic bone available at the interface. If this assumption is true, then logically there could not be more bone ingrowth than periprosthetic bone. The studies by one of us (R. D. B.) and colleagues[7] as well as by Huntsman et al.[18] showed that the volume fraction and the surface area of cancellous bone in healthy knees and hips ranges from 9 to 18 per cent. (The volume fraction is defined as the percentage of bone present in the total volume of tissue sampled.) It was expected that the volume of bone growth into the porous coating would also fall within this range.

The observation by Peters et al.[23] that polyethylene particles can migrate along screws provided the basis for the third hypothesis, which was that screws and screw-holes would provide a path for migration of particulate debris that would subsequently lead to osteolysis in these regions.

Materials and Methods

Seven anatomical porous replacement acetabular components (Intermedics Orthopedics, Austin, Texas) that had been retrieved from five cadavera at autopsy form the basis of this study. The porous coating is a cancellous-structured commercially pure titanium with an average pore size of 500 micrometers and a porosity of 51 per cent. Three components had been positioned with two screws; one component, with three screws; and two components, with four screws; the seventh component had no screws. Each component also had two to eight empty screw-holes: one component had eight empty screw-holes, one had six, four had three, and one had two. The average age of the patients (and the standard deviation) at the time of death was 57 ± 14 years (range, thirty-five to seventy-one years). The implants were *in situ* for an average of 38 ± 21 months (range, ten to sixty-four months) (Table I).

All operations had been performed by one of us (L. D. D.), an orthopaedic surgeon, according to a standardized operative approach with the use of instruments specifically designed for the implants[13]. At postmortem retrieval, the acetabulum was resected with the implant *in situ* to ensure that the implant-bone interface remained undisturbed. Gross photographs and contact radiographs were made of the specimens, which were then fixed in 70 per cent ethanol, dehydrated in ascending grades of ethanol, infiltrated, and embedded in methyl-

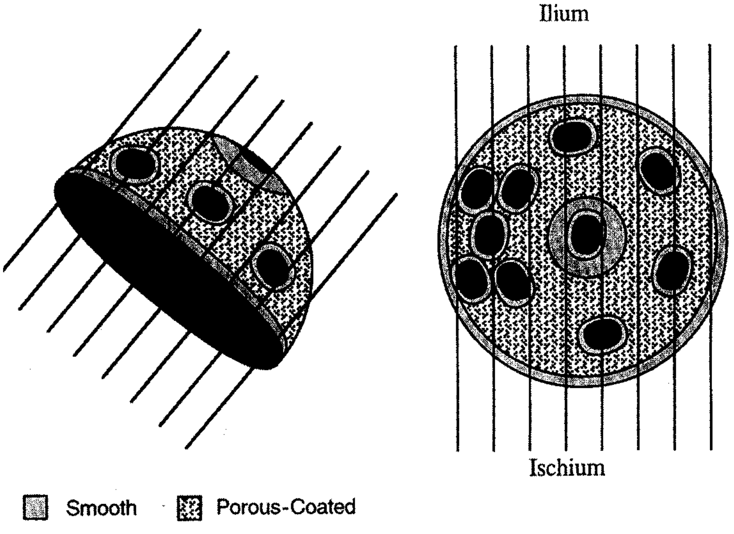

FIG. 1

Illustrations showing the orientation of the sections cut from the acetabular components.

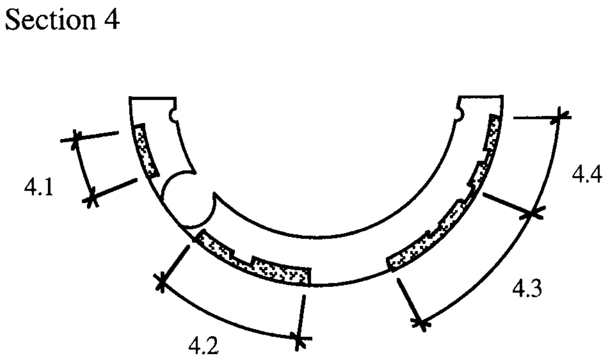

FIG. 2

Illustration of a section of an implant visually divided into regions. For example, 4.3 represents region 3 of section 4.

methacrylate[14,28]. The polymerized blocks were cut serially into three-millimeter-thick sections on a custom, water-cooled, high-speed cut-off saw[4]. An average of nine sections per acetabulum were cut perpendicular to the opening of the cup, from superior to inferior (Fig. 1).

Contact Microradiographic Analysis

Contact microradiographs were made of each section with high-resolution film (Kodak SO343; Eastman Kodak, Rochester, New York) at fifty-five kilovolts and 1.0 milliampere for 1800 seconds in a radiography cabinet (Torrex 120D; Scanray, Hawthorne, California)[5]. The microradiographs were used to calculate an appositional bone index for all sections of each component. The microradiographs were viewed under eight times magnification on a light box and were measured with a calibrated, handheld digital caliper (CD-6B; Mitutoyo, Tokyo, Japan). The total linear length of the porous coating (ΣL_1) of each section was measured, as was the total linear length of bone that appeared to be in direct contact with the porous coating. The lengths of radiolucent lines that were interposed between the bone and the implant (ΣL_2) were subtracted, causing a lower appositional bone index. The appositional bone index for the entire component was then calculated as the percentage of bone that appeared to be in direct contact with the porous-coated regions of the component: appositional bone index = $([\Sigma L_1 - \Sigma L_2]/\Sigma L_1) \times 100$ per cent. While not as accurate as backscattered electron image analysis, as a result of the projection effect of the three-millimeter sections, this method provides a good indication of the over-all apposition of bone to the surface of the implant as well as of the amount of radiolucency at the bone-implant interface. (The projection effect is the superimposition of multiple tissue layers. The magnitude of the errors caused by this is related to the thickness of the specimen[1].) The appositional bone index was developed because it is more accurate than determinations of bone apposition and the presence of radiolucent lines made from clinical radiographs, which have comparatively larger errors due to the projection effect.

The microradiographs were also examined grossly for osteolysis near screws, along the screw tracks, and adjacent to empty screw-holes. All screw-holes, whether or not they contained a screw, were accounted for and examined.

Statistical analysis (Number Cruncher Statistical System, version 6.0; J. L. Hintze, Kaysville, Utah) was performed with chi-square analysis and the Fisher exact test to determine the significance of osteolysis in empty screw-holes, holes with canted screws, and holes with seated screws. Canted screws are those that are off-angle to the perpendicular plane of the metal backing of the acetabular component.

Backscattered Electron Microscopy

The sections were ground and polished to an optical finish with a variable-speed grinding wheel (Buehler, Lake Bluff, Illinois) and were sputter-coated with a conductive layer of gold for approximately one minute with a Hummer-VI-A sputter unit (Anatech, Alexandria, Virginia). The sections were then examined in a scanning electron microscope (JSM T-330A; JEOL, Peabody, Massachusetts) with the backscattered electron detector (Tetra; Oxford Instruments, Cambridge, United Kingdom) at fifty times magnification. As previously described[2], the entire porous-coated region of the component was imaged (an average of seventeen fields per section and 153 fields per component) and analyzed with a semi-automated image-analysis system (Crystal; Oxford Instruments, Foster City, California). Each image was labeled by section number and region along the entire length of the porous coating at the time that it was made, which allowed each image to be traced back to its point of origin (Fig. 2). Comparison of the results for the different regions of a component helped us to determine if the amount of bone ingrowth or periprosthetic bone was influenced by anatomical location. Bone ingrowth was measured as the per cent

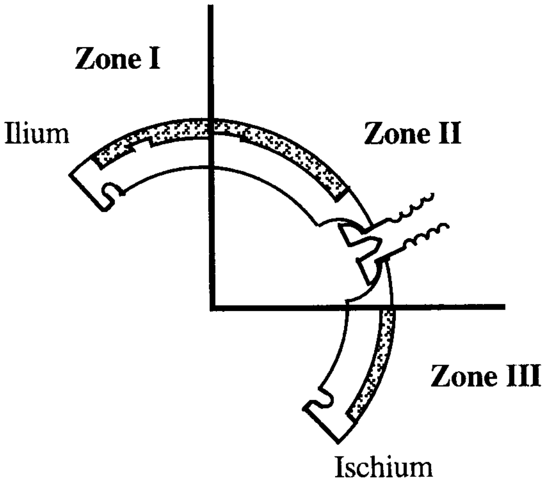

FIG. 3

Illustration of a cut section, showing the three zones delineated by DeLee and Charnley[11].

volume fraction of bone in the total volume of available pore space over all of the sections of all seven components. Similarly, the periprosthetic bone was measured as the per cent volume fraction of bone directly outside of the porous coating over all sections of all components. Three zones in each section were labeled, as described by DeLee and Charnley[11] (Fig. 3): zone I was superior, zone II was medial, and zone III was inferior.

Statistical analysis was performed with a paired t test (StatView; Abacus Concepts, Berkeley, California) to compare the percentages of bone ingrowth and periprosthetic bone. Statistical analysis (Number Cruncher Statistical System, version 6.0) of the data from the three zones delineated by DeLee and Charnley[11] demonstrated that the data were normally distributed; therefore, analysis of variance and the Newman-Keuls multiple comparison test were used to test for significant differences among the three zones. The level of significance was $p < 0.05$.

Histological Analysis

After the backscattered electron analysis was completed, the polished surfaces of sixteen sections were attached to plastic slides (Wasatch Scientific, West Valley City, Utah), ground to a thickness of approximately fifty to seventy micrometers, stained with Sanderson rapid bone stain (Surgipath Medical Industries, Richmond, Illinois)[6], and examined at 200 times magnification for particles of debris as well as soft-tissue and cellular response with the use of polarized and light microscopy. The sections were selected for histological analysis on the basis of the presence of screws, screw-holes, and radiolucent lines. If there were any unusual radiolucent lines on the microradiographs or the backscattered electron images, then these sections were also included in the histological review. Careful histological analysis was made of the screws, the screw-holes, and the outer margins of the implant for possible regions of osteolysis. If there were no abnormal bone responses, radiolucent lines, or suspected regions of osteolysis, the section was not reviewed histologically. Osteolysis was defined histologically by regions of bone loss with irregular surfaces of bone containing macrophages, giant cells, and fibrous connective tissue as well as particles of debris. The regions were graded as 0, 1+, 2+, or 3+ on the basis of the number of metal or apparent polyethylene particles or the number of giant cells or macrophages found in the observation field, according to the system of Dorr et al.[12]. A grade of 3+ indicated the greatest number of particles or cells.

TABLE II

APPOSITIONAL BONE INDEX, BONE INGROWTH, AND PERIPROSTHETIC BONE

Case	Appositional Bone Index *(Per cent)*	Bone Ingrowth *(Per cent)*	Periprosthetic Bone* *(Per cent)*
1	72	4	29
2	85	10	39
3			
R	89	9	37
L	93	17	56
4			
R	74	15	26
L	82	5	31
5	93	21	NA
Average and standard deviation	84 ± 9	12 ± 6	36 ± 11

*NA = not available.

Results

Contact Microradiographic Analysis

The contact microradiographs of the seven components revealed an average appositional bone index (and standard deviation) of 84 ± 9 per cent (range, 72 to 93

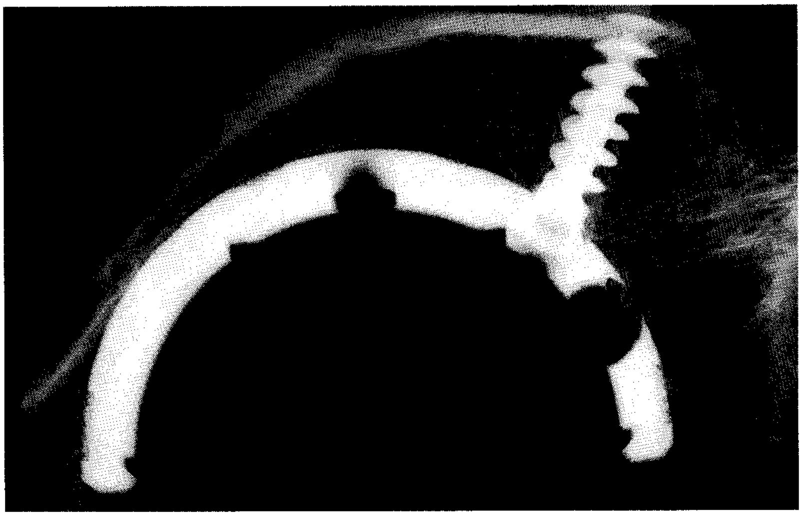

FIG. 4

Microradiograph of a section, demonstrating a high appositional bone index (93 per cent) and a well seated screw. Bone apposition was good in all regions, and there were no apparent signs of osteolysis.

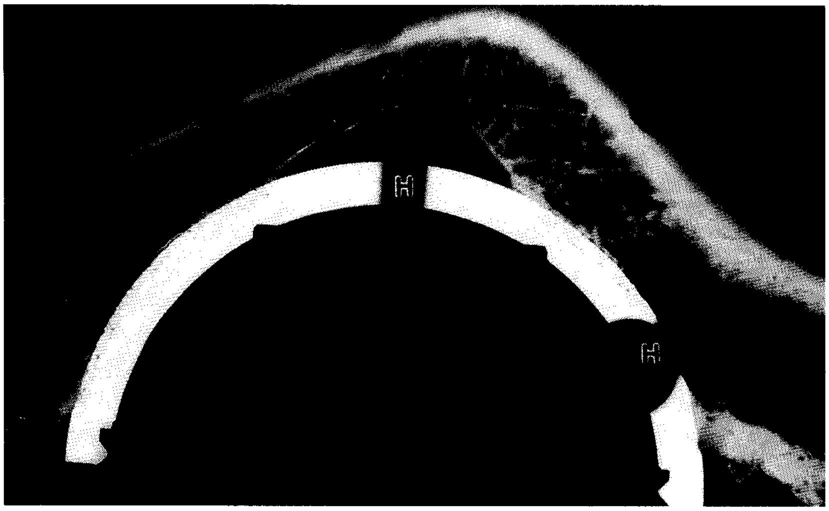

FIG. 5

Microradiograph of a section of the component that had been implanted without screws but that had a loose polyethylene insert, demonstrating an appositional bone index of 75 per cent for this section and focal osteolysis at the empty screw-holes (H).

per cent) (Fig. 4; Table II). Randomly dispersed radiolucent zones (0.2 to 0.5 millimeter in thickness) were between the remaining 16 per cent of the porous coating and the bone. The component that had been implanted without screws had an appositional bone index of 93 per cent, which was greater than the average for the series.

Inspection of the microradiographs showed that, of the forty-five screw-holes, twenty-eight (62 per cent) were empty at the time of analysis, seven (16 per cent) had a screw that was well seated, and ten (22 per cent) had a canted screw. Osteolysis was observed adjacent to six (21 per cent) of the twenty-eight empty holes (Table III), three of the seven holes with a seated screw, and six of the ten holes with a canted screw (Table IV). The type of screw-hole (empty or containing a seated or canted screw) was significantly related to the presence of osteolysis (p = 0.0003; chi-square analysis).

We tested the hypothesis that the empty screw-holes would be the least likely to be associated with osteolysis since there was no screw-head to cause potential fretting corrosion with the hole. We were unable to determine, with the numbers available, a significant difference between the prevalence of osteolysis associated

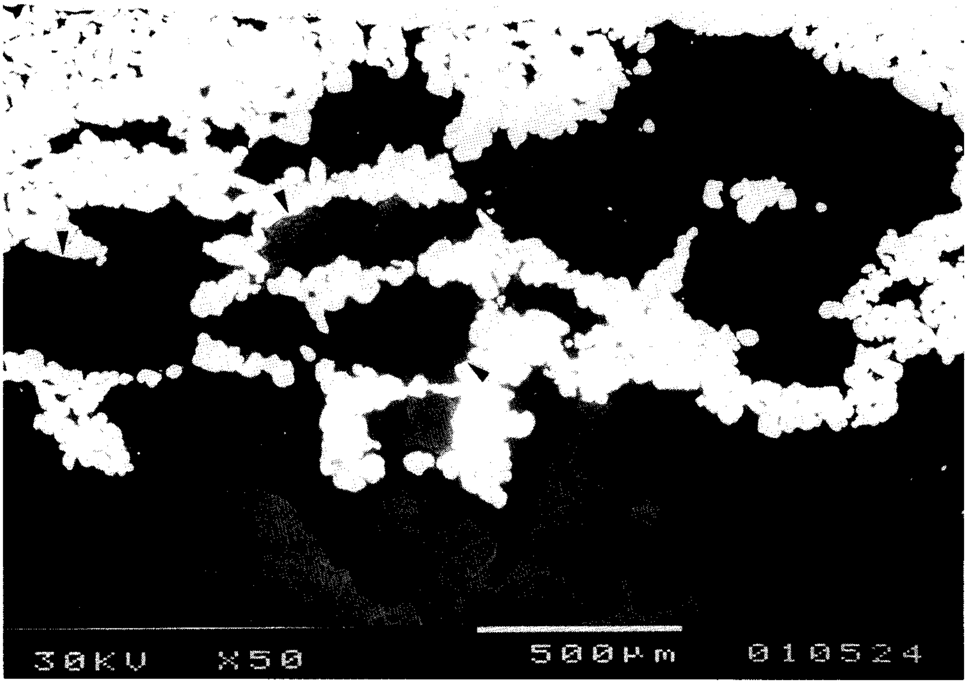

FIG. 6

Backscattered electron photomicrograph of a region exhibiting osseointegration of the porous coating (arrowheads) and a large area of periprosthetic bone (neocortex) at the interface.

TABLE III
NUMBER OF EMPTY SCREW-HOLES AND THOSE WITH A SCREW IN EACH ZONE[11]

	Over-All				Evidence of Osteolysis				No Evidence of Osteolysis			
	Zone I	Zone II	Zone III	Total	Zone I	Zone II	Zone III	Total	Zone I	Zone II	Zone III	Total
Empty screw-holes	12	8	8	28	2	1	3	6	10	7	5	22
Screws	10	1	6	17	5	0	2	7	5	1	4	10

with the holes with a seated screw and that associated with the empty holes (p = 1.000; Fisher exact test). In contrast, the holes with a canted screw were associated with a significantly higher prevalence of osteolysis than the empty holes (p = 0.043). There was no significant difference in the prevalence of osteolysis between the holes that had a canted screw and those that had a seated screw (p = 0.134).

Focal osteolysis was observed around some of the empty screw-holes of the one component that had been implanted without the use of screws (Fig. 5). In some of the specimens, bone either had been impacted into the screw-hole or had grown into the screw-hole. In the components with seated screws, osseointegration of the screw threads was observed.

Backscattered Electron Microscopy

Backscattered electron image analysis demonstrated an average volume fraction of bone ingrowth (and standard deviation) of 12 ± 6 per cent (range, 4 to 21 per cent) for the seven components (Table II). For the component that had been implanted without screws, the average bone ingrowth was 21 per cent, which was greater than the average for the series. Backscattered electron imaging also revealed osseointegration of the porous coating (Fig. 6) as well as of the threads of the well seated screws.

For the seven components, there was an average of 14 ± 10 per cent (range, 2 to 28 per cent) bone ingrowth in zone I[11], 11 ± 4 per cent (range, 6 to 15 per cent) in zone II, and 13 ± 5 per cent (range, 4 to 18 per cent) in zone III (Fig. 7). With the numbers available, there was no significant difference with regard to bone ingrowth among the three zones ($p > 0.05$).

The average volume fraction of periprosthetic bone adjacent to the porous coating was 36 ± 11 per cent (range, 26 to 56 per cent). The percentage of periprosthetic bone was determined for only the first six components, as the remaining component was prepared for histological analysis before the analysis of periprosthetic bone was completed. There was an average of 24 per cent (range, 11 to 39 per cent) more periprosthetic bone than bone ingrowth, which was a significant difference ($p < 0.05$).

Histological Analysis

Particles of polyethylene (2+) and metal (3+) debris were observed along the length of six of the ten canted screws. The particles of debris (0.5 to one micrometer in maximum length) were contained within a 0.2 to one-millimeter-wide region by a composite fibrous connective tissue and boundary of bone sometimes referred to as the neocortex. Few macrophages (1+) and giant cells (1+) were observed.

The threads of the seven well seated screws were osseointegrated. Bone marrow was observed adjacent to the threads where bone did not abut them. Particles of polyethylene (2+) and metal (3+) debris were seen in

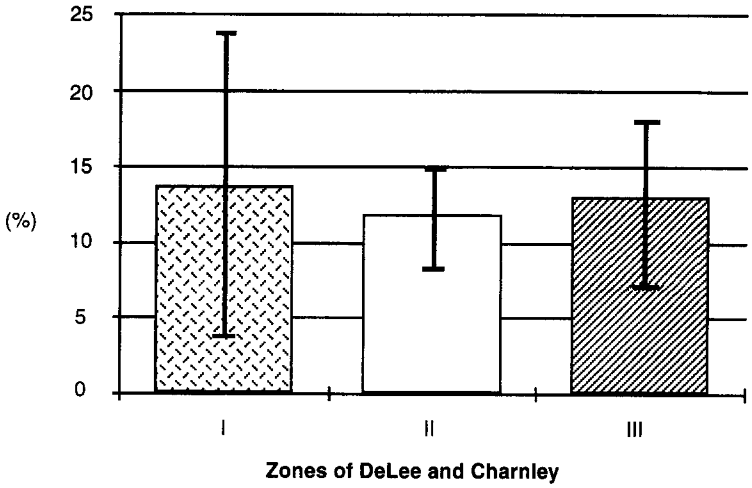

FIG. 7

TABLE IV

NUMBER OF CANTED OR SEATED SCREWS IN EACH ZONE[11]

	Over-All				Evidence of Osteolysis				No Evidence of Osteolysis			
	Zone I	Zone II	Zone III	Total	Zone I	Zone II	Zone III	Total	Zone I	Zone II	Zone III	Total
Canted Screws	8	0	2	10	4	0	2	6	4	0	0	4
Seated Screws	2	1	4	7	2	0	1	3	0	1	3	4

the synovial fluid that had pooled between the screw-head and the polyethylene liner when the head was seated (Fig. 8).

Histological analysis confirmed that 21 per cent (six) of the twenty-eight empty screw-holes were associated with osteolysis. Two of the twelve holes in zone I[11], one of the eight holes in zone II, and three of the eight holes in zone III were associated with an osteolytic region (Table III). Each of the acetabular components had at least two empty screw-holes adjacent to a region of osteolysis.

In one specimen, the polyethylene liner was visibly mobile when the rim of the insert was pushed with a hemostat at the time of autopsy. This demonstrated evidence of a so-called pistoning effect by the liner, which may have caused the large deposits of particulate polyethylene (3+) and metal (3+) debris in the region of the hole. There was also a large number of macrophages (3+) and giant cells (3+) in these regions (Fig. 9).

No particles of debris were evident in areas in which bone ingrowth had occurred. Evaluation of regions of fibrous-tissue attachment demonstrated a predominant fibroblast and collagen network within the porous coating. Particles of polyethylene debris (2+; one to seventy-five micrometers in maximum length) and metal debris (3+; 0.5 to one micrometer in maximum length) were observed in the fibrous tissues along the outer margins of the implants, as they were along the length of the screws.

Discussion

Several observations were made on the basis of the results of this investigation. The first hypothesis that we considered was that bone ingrowth might be preferential, occurring in greater amounts in the superior region of the implant (zone I[11]). This hypothesis originated from the common observance of preferential wear in the superior hemisphere of the polyethylene insert of retrieved implants and the effect of preferential loading on the organization and remodeling of bone[9,30,31]. However, our results show that bone ingrowth did not respond to preferential loading superiorly; instead, the components had uniform bone ingrowth throughout. Carter et al.[8] noted that a metal-backed implant provided a more uniform distribution of stresses by maintaining stiffness, as opposed to a ce-

FIG. 8

Polarized light photomicrograph showing metal (black) and polyethylene (arrowheads) particles of debris in the synovial fluid exudate that had pooled between the screw-head and the polyethylene liner (Sanderson rapid bone stain, × 200).

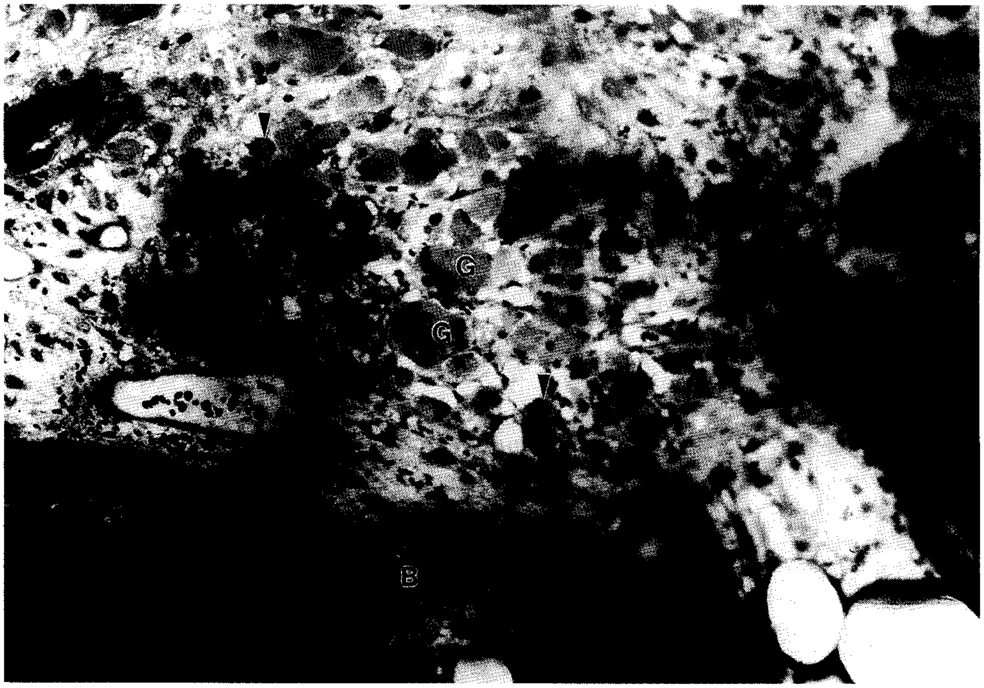

FIG. 9

Light photomicrograph showing macrophages (arrowheads) and giant cells (G) in regions around the screw-holes where large quantities (3+) of debris were observed (Sanderson rapid bone stain, × 200). B = bone.

mented all-polyethylene component that had concentrated stress fields. This finding, along with good initial fit and coverage, may explain why bone ingrowth was similar among the three zones[11] in our study. Pidhorz et al.[24] reported on a series of eleven acetabular components that had been implanted with screws and without cement and were retrieved postmortem. The average volume fraction of bone ingrowth (and standard deviation) was 12.1 ± 8.2 per cent, which is similar to the average volume fraction of 12 ± 6 per cent in our study, and the bone ingrowth was determined to be uniform in the nine defined anatomical regions of the components. It was briefly noted that, when more radiolucent lines were seen on the radiographs, less ingrowth was seen[24]. The uniformity of the bone in apposition to the implant was observed in our study during contact microradiographic analysis as well as during the corresponding high-resolution backscattered electron image analysis.

The second hypothesis examined was based on the initial assumption made by Pidhorz et al.[24] that the maximum possible value for bone ingrowth is 100 per cent. They later stated in the same article, however, that this may be neither possible nor desirable. As a corollary, we hypothesized that there would be equal amounts of bone within the porous coating and at the interface. Since human cancellous bone is not solid but rather is a porous structure, 100 per cent bone ingrowth into the porous coating is not possible. One of us (R. D. B.) and colleagues[7] as well as Huntsman et al.[18] found the volume and area fraction of human cancellous bone in the proximal aspects of femora and tibiae to range from 9 to 18 per cent. This corresponds to the 12 per cent and 12.1 per cent average volume fraction of bone ingrowth within the porous coating observed in the present study and in that by Pidhorz et al., respectively. It may be that cancellous bone is limited to forming a given volume of bone.

Our investigation (of six components) determined that there was, in all cases, a greater amount of periprosthetic bone than ingrown bone, which disproves our second hypothesis. It is possible that when the surgeon prepares the bone for the implantation the resulting bone chips cluster at the interface, effectively increasing the amount of periprosthetic bone and allowing the commonly observed neocortex to be formed in that region. This may explain the increased amount of bone in apposition to the implant (an average appositional bone index of 84 per cent). The inherent stability of the neocortex is demonstrated by the lack of a linear pattern of osteolysis at the implant-bone interface. There was no such osteolysis along the interface caused by polyethylene particulate debris, as was seen by Schmalzried et al.[29]. Those authors attributed the loosening of cemented acetabular components to this linearly progressive destruction of the interface. It could be argued that as long as a large area (all three zones[11]) of the surface of the implant is osseointegrated, as observed in the present study, the component may be sufficiently stable to be clinically successful even with limited bone growth in the porous coating. Additional investigations are needed to confirm this hypothesis.

The average 12 per cent bone ingrowth and 84 per cent appositional bone index measured in the present study indicate that the components were stable. The presence of bone in the porous coating over large regions of the implant is also thought to stabilize the implant and to maintain this stability. Pilliar et al.[25,26] found that large displacements between the implant and the bone prevent bone ingrowth. Søballe et al.[32] supported this finding and demonstrated that bone ingrowth was affected by micromotion at the implant-bone interface and that micromotion should be limited to less than 150 micrometers in order to achieve and maintain bone ingrowth.

The third hypothesis involved the effect of screws and screw-holes on bone ingrowth. Cook et al.[10] compared porous-coated acetabular components fixed with screws with those fixed with pegs or spikes. Their results showed a decrease in radiolucent lines and an increase in bone growth in the components with screws. Their study was limited, however, by the use of components retrieved at revision operations rather than at autopsy. Cook et al. concluded that the pegs or spikes may have prevented complete seating of the component on the periprosthetic bone and that greater quantities of bone ingrowth and more uniform ingrowth occurred in the acetabular components for which screws had been used for the initial fixation. One of us (R. D. B.) and colleagues[3] showed that human bone must be within fifty micrometers of the porous coating to ensure bone growth into implants. Screws assist in securing and maintaining the implant against the bone, ensuring such bone ingrowth. In contrast, pegs may interdigitate with the bone first, preventing the porous coating from coming into contact with bone, as described by Hedley et al.[17], and leading to stress-shielding at the implant interface.

The use of screws was associated with complications in the present investigation. Of the seven screws with adjacent osteolysis, which was observed on microradiographic and histological examination, five were in zone I[11]. It seems that the screws provided a pathway for the migration of particulate debris, allowing it to stream along the screw-bone interface. With the numbers available, the statistical analysis indicated that there was no significant difference between canted screws and seated screws in terms of the occurrence of osteolysis. However, the prevalence of osteolysis associated with the screw-holes with a canted screw (six of ten) was greater than that associated with the empty holes (six of twenty-nine). This suggests that, in order to prevent osteolysis, it is better to leave a screw-hole in a component empty than to insert a canted screw. The risk of osteolysis around screws must be weighed against the potential benefit of increased stability and gap closure when use of screws in an acetabular component is being considered.

Osteolysis was found near three of the eight empty screw-holes in the inferior region (zone III) and near two of the twelve empty holes in the superior region (zone I). Pidhorz et al.[24] observed that screws fretting against the metal backing of the implant may not be the sole source of particulate debris. This observation was supported by the results of the current study, which demonstrated osteolytic regions around empty screw-holes. The empty screw-holes appear to have served as reservoirs for the accumulation of particulate debris.

As mentioned, one component in the present series had been implanted without screws. The surgeon was careful to determine that a proper press-fit of the component and the acetabulum had been achieved, to ensure stability of the implant. It may be possible to eliminate fixation with screws or pegs if a press fit can be reproducibly obtained. The results of mechanical testing by Kwong et al.[21] support this hypothesis. Their results showed that an acetabular cup press fit, without screws, into a socket that had been underreamed one millimeter had considerably less relative motion than an exact-fit acetabular cup implanted with two, three, or four screws. Additional investigations of a larger sample of postmortem specimens are needed to confirm this hypothesis.

References

1. **Bachus, K. N.**, and **Bloebaum, R. D.:** Projection effect errors in biomaterials and bone research. *Cells and Mater.*, 2: 347-355, 1992.
2. **Bloebaum, R. D.; Rubman, M. H.;** and **Hofmann, A. A.:** Bone ingrowth into porous-coated tibial components implanted with autograft bone chips. Analysis of ten consecutively retrieved implants. *J. Arthroplasty*, 7: 483-493, 1992.
3. **Bloebaum, R. D.; Bachus, K. N.; Momberger, N. G.;** and **Hofmann, A. A.:** Mineral apposition rates of human cancellous bone at the interface of porous coated implants. *J. Biomed. Mater. Res.*, 28: 537-544, 1994.
4. **Bloebaum, R. D.; Merrell, M.; Gustke, K.;** and **Simmons, M.:** Retrieval analysis of a hydroxyapatite-coated hip prosthesis. *Clin. Orthop.*, 267: 97-102, 1991.
5. **Bloebaum, R. D.; Rhodes, D. M.; Rubman, M. H.;** and **Hofmann, A. A.:** Bilateral tibial components of different cementless designs and materials. Microradiographic, backscattered imaging, and histologic analysis. *Clin. Orthop.*, 268: 179-187, 1991.
6. **Bloebaum, R. D.; Sanderson, C.; McCarvill, S.;** and **Campbell, P.:** Plastic slides in the preparation of implant and tissue for interface analysis. *J. Histotechnol.*, 12: 307-310, 1989.
7. **Bloebaum, R. D.; Bachus, K. N.; Mitchell, W.; Hoffman, G.;** and **Hofmann, A. A.:** Analysis of the bone surface area in resected tibia. Implications in tibial component subsidence and fixation. *Clin. Orthop.*, 309: 2-10, 1994.
8. **Carter, D. R.; Vasu, R.;** and **Harris, W. H.:** Periacetabular stress distributions after joint replacement with subchondral bone retention. *Acta Orthop. Scandinavica*, 54: 29-35, 1983.
9. **Chamay, A.**, and **Tschantz, P.:** Mechanical influences in bone remodeling. Experimental research on Wolff's law. *J. Biomech.*, 5: 173-180, 1972.
10. **Cook, S. D.; Thomas, K. A.; Barrack, R. L.;** and **Whitecloud, T. S., III:** Tissue growth into porous-coated acetabular components in 42 patients. Effects of adjunct fixation. *Clin. Orthop.*, 283: 163-170, 1992.
11. **DeLee, J. G.**, and **Charnley, J.:** Radiological demarcation of cemented sockets in total hip replacement. *Clin. Orthop.*, 121: 20-32, 1976.

12. **Dorr, L. D.; Bloebaum, R.; Emmanual, J.;** and **Meldrum, R.:** Histologic, biochemical, and ion analysis of tissue and fluids retrieved during total hip arthroplasty. *Clin. Orthop.*, 261: 82-95, 1990.
13. **Dorr, L. D.; Absatz, M.; Gruen, T. A.; Saberi, M. T.;** and **Doerzbacher, J. F.:** Anatomic porous replacement hip arthroplasty: first 100 consecutive cases. *Sem. Arthroplasty*, 1: 77-86, 1990.
14. **Emmanual, J.; Hornbeck, C.;** and **Bloebaum, R. D.:** A polymethyl methacrylate method for large specimens of mineralized bone with implants. *Stain Technol.*, 62: 401-410, 1987.
15. **Engh, C. A.; Zettl-Schaffer, K. F.; Kukita, Y.; Sweet, D.; Jasty, M.;** and **Bragdon, C.:** Histological and radiographic assessment of well functioning porous-coated acetabular components. A human postmortem retrieval study. *J. Bone and Joint Surg.*, 75-A: 814-824, June 1993.
16. **Harris, W. H.:** 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 and Joint Surg.*, 51-A: 737-755, June 1959.
17. **Hedley, A. K.; Clarke, I. C.; Kozinn, S. C.; Coster, I.; Gruen, T.;** and **Amstutz, H. C.:** Porous ingrowth fixation of the femoral component in a canine surface replacement of the hip. *Clin. Orthop.*, 163: 300-311, 1982.
18. **Huntsman, C. I.; Zou, L.;** and **Bloebaum, R. D.:** Changes in cancellous bone of the female femoral neck and trochanteric regions with aging. *Trans. Orthop. Res. Soc.*, 20: 237, 1995.
19. **Kaiser, A. D.,** and **Whiteside, L. A.:** The effect of screws and pegs on the initial fixation stability of an uncemented unicondylar knee replacement. *Clin. Orthop.*, 259: 169-178, 1990.
20. **Keating, E. M.; Ritter, M. A.;** and **Faris, P. M.:** Structures at risk from medially placed acetabular screws. *J. Bone and Joint Surg.*, 72-A: 509-511, April 1990.
21. **Kwong, L. M.; O'Connor, D. O.; Sedlacek, R. C.; Krushell, R. J.; Maloney, W. J.;** and **Harris, W. H.:** A quantitative in vitro assessment of fit and screw fixation on the stability of a cementless hemispherical acetabular component. *J. Arthroplasty*, 9: 163-170, 1994.
22. **Mason, M. W.; Skedros, J. G.;** and **Bloebaum, R. D.:** Evidence of strain-mode-related cortical adaptation in the diaphysis of the horse radius. *Bone*, 17: 229-237, 1995.
23. **Peters, P. C., Jr.; Engh, G. A.; Dwyer, K. A.;** and **Vinh, T. N.:** Osteolysis after total knee arthroplasty without cement. *J. Bone and Joint Surg.*, 74-A: 864-876, July 1992.
24. **Pidhorz, L. E.; Urban, R. M.; Jacobs, J. J.; Sumner, D. R.;** and **Galante, J. O.:** A quantitative study of bone and soft tissues in cementless porous-coated acetabular components retrieved at autopsy. *J. Arthroplasty*, 8: 213-225, 1993.
25. **Pilliar, R. M.; Lee, J. M.;** and **Maniatopoulos, C.:** Observations on the effect of movement on bone ingrowth into porous-surfaced implants. *Clin. Orthop.*, 208: 108-113, 1986.
26. **Pilliar, R. M.; Cameron, H. U.; Welsh, R. P.;** and **Binnington, A. G.:** Radiographic and morphologic studies of load-bearing porous-surfaced structured implants. *Clin. Orthop.*, 156: 249-257, 1981.
27. **Ritter, M. A.,** and **Campbell, E. D.:** Direct comparison between bilaterally implanted cemented and uncemented total hip replacements in six patients. *Clin. Orthop.*, 207: 77-82, 1986.
28. **Sanderson, C.,** and **Kitabayashi, L. R.:** Parallel experience of two different laboratories with the initiator perkadox 16 for polymerization of methylmethacrylates. *J. Histotechnol.*, 17: 343-348, 1994.
29. **Schmalzried, T. P.; Jasty, M.;** and **Harris, W. H.:** Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space. *J. Bone and Joint Surg.*, 74-A: 849-863, July 1992.
30. **Skedros, J. G.; Mason, M. W.;** and **Bloebaum, R. D.:** Evidence of potential strain-mode-specific differences in cortical bone microstructure in a tension/compression system. *Trans. Orthop. Res. Soc.*, 18: 533, 1993.
31. **Skedros, J. G.; Bloebaum, R. D.; Mason, M. W.;** and **Bramble, D. M.:** Analysis of a tension/compression skeletal system: possible strain-specific differences in the hierarchical organization of bone. *Anat. Rec.*, 239: 396-404, 1994.
32. **Søballe, K.; Brockstedt-Rasmussen, H.; Hansen, E. S.;** and **Bünger, C.:** Hydroxyapatite coating modifies implant membrane formation. Controlled micromotion studied in dogs. *Acta Orthop. Scandinavica*, 63: 128-140, 1992.
33. **Volz, R. G.; Nisbet, J. K.; Lee, R. W.;** and **McMurtry, M. G.:** The mechanical stability of various noncemented tibial components. *Clin. Orthop.*, 226: 38-42, 1988.
34. **Wolff, J.:** *The Law of Bone Remodeling*, pp. 3-100. Translated by P. Maquet and R. Furlong. New York, Springer, 1986.