HISTOPATHOLOGY OF A WELL-FUNCTIONING HYDROXYAPATITE-COATED FEMORAL PROSTHESIS AFTER 52 MONTHS

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A fully hydroxyapatite-coated femoral implant was retrieved during autopsy. This component, provided with a bipolar femoral head, had been inserted for a displaced fracture of the femoral neck 52 months before.

***Osseointegration of the implant* was evident, without any formation of fibrous tissue : 39.9% of the perimeter of the prosthesis at the level of its proximal third was interfaced with bone (62.8% at the mid-third and 65.2% at the distal third).**

***Remodeling of bone* had ensued. Deposition of bone was most prominent in the calcar zone, along the medial and lateral aspects and around the tip. Proximally, cortical porosity was found to be increased by 73%, whereas medullary bone porosity was increased by a factor of 2.**

***Cell-mediated resorption of the coating* was systematically present in these bone remodeling areas. The average thickness of the coating was respectively 10.8, 50.2 and 151.2 µm in the proximal, mid- and distal thirds of the implant. Formation of new bone was often coupled with resorption. No debris from the coating was found in the joint tissues or in the articulating surface of the polyethylene insert.**

These overall histopathological features support mechanical stability of the implant and active remodelling of bone along with focal removal of HA coating associated with osteoclastic activity. No side effects from coating degradation could be demonstrated.

Keywords : hydroxyapatite ; human explants ; histology ; osseointegration.

Mots-clés : hydroxyapatite ; explants humains ; histologie ; ostéointégration.

INTRODUCTION

Attachment of load-bearing prosthetic devices to the musculoskeletal system is a major problem in prosthesis implantation. A number of materials have been investigated to overcome this problem. Among these, calcium phosphate ceramics, and particularly hydroxyapatite (HA), are appealing for clinical use by virtue of their osteophilic nature. HA is reported to be a bioactive material (33). It shows bonding osteogenesis, which means that bone deposition starts at, and proceeds away from, the HA surface. The establishment, by physiochemical processes, of continuity between the implant and the bone matrix ensues (39). This property of HA to guide bone formation on the surface of an implant provided it is implanted in a bony environment is known as osteoconduction (24).

Retrieval studies, providing human histological data of the bone-HA interface, are scarce (table I). This scarcity is due to the difficulty in obtaining and processing human specimens, especially those specimens in which the femur is retrieved intact

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Table I. — Retrievals of HA-coated femoral components

Author	Year	Femoral Component	Fully coated : F Proximally coated : P	N. of retrievals	Age (years)	Pathology	Delay in implantation
Osborn (32)	1987	Furlong-Osprovit	F	1	80	??	7 weeks
Wicki *et al.* (38)	1990	MR Titan-Mecron	F	2	??	??	3-4 weeks
Bloebaum *et al.* (3)	1991	APR-Intermedics	P	1	61	osteoarthritis	3 weeks
Furlong *et al.* (19)	1991	Furlong-Osprovit	F	4	??	?	10 days 17 days 7 weeks 19 weeks
Hardy *et al.* (22)	1991	Corail-Landos	F	4	80 80 74 83	fracture fracture fracture fracture	6 weeks 3 months 5 months 6 months
Bauer *et al.* (1)	1991	Omnifit-Osteonics	P	5	50 54 50 37 37	osteoarthritis revision arthro- plasty osteoarthritis avasc.necrosis avasc.necrosis	4.5 months 6 months 9 months 14 months 25 months
Bloebaum *et al.* (5)	1993	APR-Intermedics	P	1	35	juvenile rheum. arthritis	19 months
Frayssinet *et al.* (17)	1993	Corail-Landos	F	10	56-90	fracture	from 5 days to 26 months
Hardy *et al.* (23)	1994	Corail-Landos	F	2	83 88	fracture fracture	24 months 26 months
Lintner *et al.* (26)	1994	AHS-Osprovit	P	1	80	fracture	10.4 months
present report	1998	*Corail-Landos*	*F*	*1*	*74*	*fracture*	*52 months*

with the implanted prosthesis. These studies confirm the osteoconductive properties of HA in human hips. All the specimens obtained after at least one year of implantation display resorption of the coating. At least one question of paramount importance remains unsolved : does progressive resorption of the coating lead to loosening of the implant ? The only way to address this question is to obtain histopathological data from retrievals obtained after a long implantation time.

The purpose of this paper is to report the histological findings of a well-functioning femoral prosthesis retrieved after 52 months of implantation.

MATERIAL AND METHODS

Endoprosthesis

The femoral component (Titan Corail, Landos, France) is designed as a self-locking stem made of titanium-aluminium-vanadium alloy. It presents multiple grooves, horizontal in the proximal third and vertical in the distal two thirds, in order to increase primary stability. A coating of HA is plasma-sprayed on the whole surface of the implant. Characterization of the coating is summarized in table II. The implant is provided with a stainless steel 28 mm femoral head and a bipolar femoral cup (BHP, Zimmer, Swindon, UK), the diameter of which is equal to that of the excised femoral head.

Case report

A very active 74-year-old male patient was admitted for treatment of a displaced fracture of the left femoral neck. The prosthesis described above was inserted (size 10) through a posterior approach. Immediate full-weight bearing was authorized. The patient returned to his pretraumatic condition after two months. His hip was totally pain-free, and he walked up to ten kms per day without crutches and without any discomfort. Four years and four months later, he suddenly died of a myocardial infarction.

Retrieval of the implant

The explant, comprising of the whole acetabulum, the joint tissues and the proximal half of the femur, was retrieved *en bloc*, according to our standard protocol (22). After radiography, the joint was opened. The acetabular bone, the capsular tissue and the femur were dissected, isolated from each other and immediately fixed in Karnovsky's solution (cacodylate buffer containing 2% formaldehyde and 2% glutaraldehyde, pH = 7.4). The metallic shell, the polyethylene insert and the femoral head of the prosthesis were immersed in physiologic saline.

Histologic processing

The femur was cut into three parts, which were fixed in 4% formaldehyde solution in phosphate-buffered saline (PBS) for three weeks. The fragments were dehydrated in alcohol solutions and embedded in polymethylmethacrylate. Two-millimeter thick sections were made, using a low-speed cooled diamond saw. The sections were re-embedded at the surface of a polystyrene block and ground to a 50- to 100 µm thickness using a LamPlan MM 823 Polisher. Twelve sections were made through the prosthesis, and four sections of special interest were chosen to perform the histomorphometric measurements. Sections studied using a transmitted or reflected light microscope (Reichert Polyvar) were stained with a fuchsin-toluidine solution (18). Ultrathin sections studied using a scanning electron microscope (SEM) were gold-palladium coated and examined using the backscattered mode of a HITACHI 4000 SEM operating at a voltage of 15 kV.

Longitudinal sections were made in the calcar and trochanteric interfacial regions after the metal was mechanically removed from the sample. Seven micrometer thin sections were then made using a calcified tissue microtome (Reichert type E). These sections were stained with fuchsin-toluidine or Goldner trichrome.

The histomorphometric measurements were made by an image analysis device (Graftek software). The extent of bone coverage was measured using the bone affinity index (the length of bone directly apposed to the implant / the total length of the bone implant interface x 100). The porosity of cortical bone and medullary bone was determined in areas of interest. The results were expressed in percentage of the total area measured. The coating thickness was measured every 500 µm on the implant perimeter along a 5 mm length located on each side of the implant. The maximum, minimum and average coating thicknesses were recorded.

The polyethylene insert was rinsed in running tap water, critical-point dried and sputter-coated with gold prior to examination in a JEOL JSM 820 equipped with a Tracor Northern 5550 EDX analytical system.

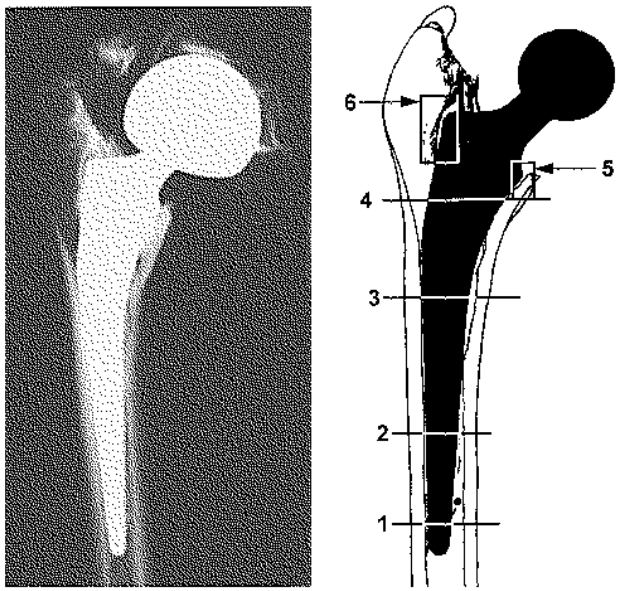

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Fig. 1a. — Radiograph of the femur. *b.* — Location of the 6 main sections made through the implant.

RESULTS

Radiographic evaluation

The contact radiographs of the specimen (fig. 1) reveal a well-fixed implant in slight varus, without any cortical thickening, cortical resorption, or osteolysis, especially in the metaphyseal area. A dense line 7 mm above the superolateral edge of the prosthesis reflects subsidence of the implant in the early postoperative period. Four zones of particular interest are identified :

1) the tip of the stem, where bridges of bone extend from the endosteal surface of bone toward the surface of the implant (section 1)
2) the diaphyseal area, where the stem displays intimate contact with the femoral cortices (sections 2 and 3)
3) the calcar area, where prominent bone apposition is found (section 4). A short radiolucent

line, suggesting osteolysis, is observed at the top of this calcar area (section 5).

4) the trochanteric area, where a vertical radiolucent line is identified (section 6).

Histologic Analysis

Qualitative Results. At the tip level (section 1), nearly the whole stem perimeter is covered by bone tissue. The interface most commonly found (fig. 2) consists of bone buttressed by radiating trabeculae, connected to the cortical bone through the bone network of the spongiosa. Their length (reflecting the periprosthetic gap) varies between 0.4 and 3.2 mm. These trabeculae are encountered at the stem surfaces closest to the endosteum. The opposite aspect (*i.e.* the anterior one) is covered by bone layers parallel to the surface. Marked osteoporosis is notable in the anterior and posterior cortices.

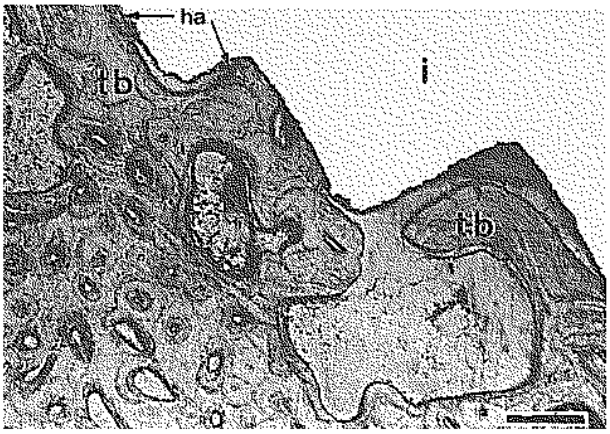


Fig. 2. — Dense trabecular bone (tb) bridging cortical bone to HA coating (ha). Implant : i. Reflected light microscopy, unstained. Bar = 550 µm.

The diaphyseal sections (sections 2 and 3) show isolated bone trabeculae running from the endosteum to the surface of the medial and the lateral aspects of the implant, while the anterior and the posterior ones are covered by thin and continuous bone layers running parallel to the stem surface. The porosity of the posterior cortex is markedly increased.

At the metaphyseal level (section 4), interconnected bone trabeculae are found on the medial and the lateral aspects of the implant. Increased density of this cancellous bone is evident around the corners, where trabeculae are broader and more intercalated with each other. The bone is apposed either at the contact of coating remnants or at the surface of the sandblasted metal (fig. 3). No bone can be found on the anterior and the posterior sides. HA particles are found phagocytosed by cells from the marrow cavity or totally integrated within the newly formed bone trabeculae (fig. 4). Cancellization of the anterior and medial cortices is evident, while the lateral one remains surprisingly dense.

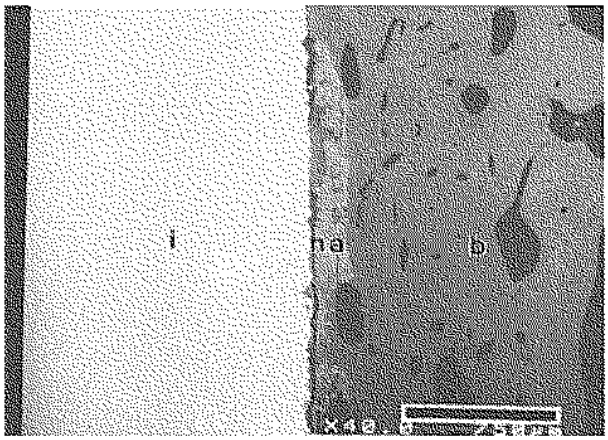


Fig. 3. — Bone (b) apposed either at the surface of a degraded HA coating (ha) or at the sandblasted metal contact (i). SEM under a backscattered mode. Bar = 750 µm.

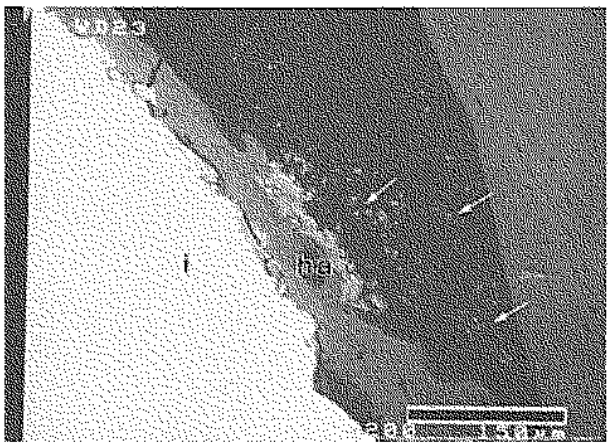


Fig. 4. — HA-coating fragments (ha) are either integrated within the lamellar bone or dispersed in the bone marrow cavity and phagocytosed by histiocytes (arrows). Implant : i. SEM under a backscattered mode. Bar = 150 µm.

At the most proximal part of the prosthesis, in the calcar area (section 5), a pouch exists between the prosthesis and the bone. It is filled with connective tissue made of macrophages and mastocytes. The macrophages contain metal particles. Some osteoclasts are found resorbing the bone tissue.

The lucent line found along the trochanteric side (section 6) has a different structure. It is formed by a dense connective tissue with hyaline zones containing mostly fibroblasts and very few clustered macrophages having phagocytosed particles (fig. 5). The EDX analysis shows that these particles are composed of metal (stainless steel and titanium) and even Si-Mg. The number of particles is very small. Some osteoclasts are found at the bone interface and within the haversian canals showing an irregular and enlarged shape. Osteoid tissue covers the majority of the bone surface and does not show apposed osteoblasts.

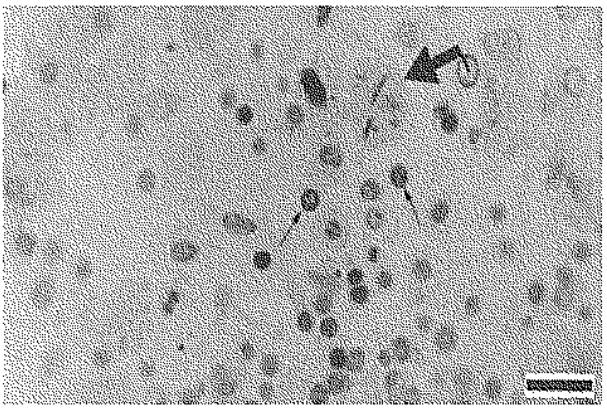
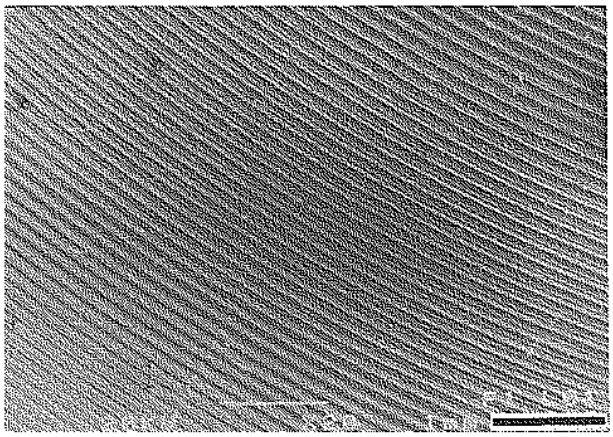


Fig. 5. — Cell agglomeration in the fibrous tissue found in the peritrochanteric radiolucent line. Few macrophages containing metal particles (large arrow) and many lymphocytes (small arrows) are found. Transmitted light microscopy. Fuchsin-toluidine stained. Bar = 50 µm.

Examination of the articulating surface of the polyethylene insert shows abrasion of the grooves originally present on the implant (fig. 6) and resulting from the manufacturing process. Numerous scratches crossing these grooves are identified. In some of them, particles are found embedded in the polyethylene. Xray diffraction (EDX) on these particles shows their metallic nature (peaks



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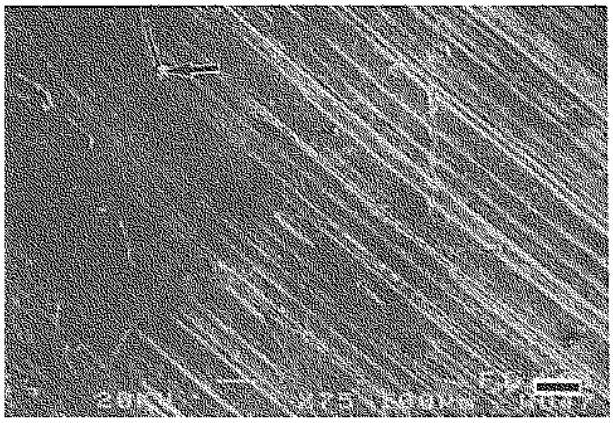

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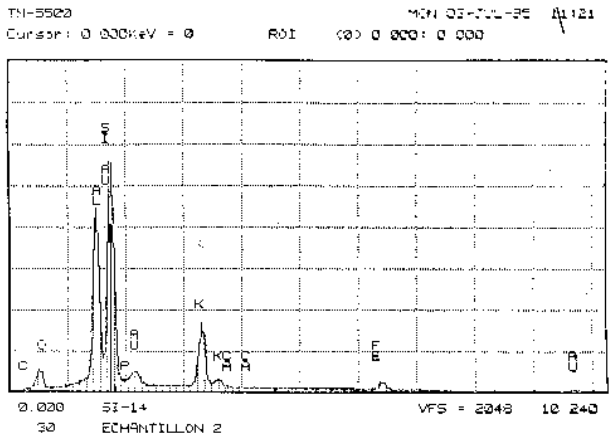

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Fig. 6a. — Articulating surface of the polyethylene insert before implantation. The grooves result from the manufacturing process. SEM. Bar = 1 mm. *b.* — Articulating surface of the polyethylene insert after explantation. Abrasion of the grooves and scratches due to third-body wear are found (arrow). SEM. Bar = 100 µm. *c.* — X ray diffraction graph of the particle found in the polyethylene insert. A peak of Al is clearly visible.

of Al and Fe). Absence of Ca and P peaks is noteworthy.

Quantitative results

Host-prosthesis interfaces (table III). Four types of interfaces are identified : *a)* HA/bone, *b)* sandblasted metal/bone, *c)* HA/bone marrow and *d)* sandblasted metal/bone marrow. The affinity index, expressed as the sum of a) and b), is higher in the distal sections (65.2% and 62.8%) than in the proximal ones (39.9%).

Coating resorption (table IV). The HA coating at the tip is not significantly altered. Its thickness is similar to the nominal thickness at the time of manufacture (table II). In contrast, the coating at the metaphyseal level is almost completely resorbed. Some remnants are still found on the stem surface. In the regions where bone is not in close contact with the implant, the coating is resorbed. The mean coating thickness at this level is decreased, and the standard deviation is very high, suggesting that most of the stem surface at this level is no longer coated with HA.

Cortical porosity (table V). The porosity of the cortical bone varies greatly both in the same section and at different section levels. On the whole, it is increased by a factor of 1.7 in the proximal part. The porosity of the lateral cortex is found to be minimal in all the sections. The

Table II. — Characterization of the HA coating

Plasma-sprayed powder	HA : > 98%
Crystallographic structure of the coating	Calcium hydroxyapatite : $Ca_{10}(PO_4)_6(OH)_2$: > 95% Tricalcium phosphate : trace Calcium oxide : trace
Crystallinity	65% ± 10%
Coating thickness	155µ ± 35µ
Trace elements	As : < 3 ppm Cd : < 5 ppm Hg : < 5 ppm Pb : < 3 ppm
Porosity	5%
Tensile strength	35 MPa (pull-out test)

Table III. — Different interfaces found at the prosthesis/tissue interface

	Section 1	Section 2	Section 4
Total perimeter measured	31572 µm	46238 µm	60653 µm
1. Bone / HA interface	20593 µm (65.2%)	15969 µm (34.5%)	21749 µm (35.9%)
2. Bone / Metal interface	0 µm (0%)	13084 µm (28.3%)	2436 µm (4%)
Bone-Affinity Index (= 1+2)	20593 µm (65.2%)	29053 µm (62.8%)	24185 µm (39.9%)
3. Bone marrow / HA interface	10979 µm (34.8%)	3501 µm (7.6%)	7454 µm (12.3%)
4. Bone marrow / Metal interface	0 µm (0%)	13684 µm (29.6%)	29014 µm (47.8%)

Table IV. — Thickness of the HA coating (minimum, average ± standard deviation and maximum values)

Thickness of the coating	Section 1	Section 2	Section 3	Section 4
minimal	73 µm	0 µm	0 µm	0 µm
average ± SD	151.2 µm ± 34.6	50.2 µm ± 59.9	34.2m ± 100.1	10.8µm ± 49.1
maximal	200 µm	147 µm	150 µm	94.1 µm

Table V. — Porosity measurements of the cortical bone in different sections

	Section 1	Section 2	Section 3	Section 4
Anterior side	17.5%	11.8%	11.3%	19.8%
Posterior side	17.4%	30.3%	26.6%	35.1%
Medial side	5.8%	7.5%	16.1%	23.1%
Lateral side	5.1%	4%	3.3%	3%
TOTAL	11.7%	13.4%	14.3%	20.2%

Table VI. — Porosity measurements of medullary bone in different sections

	Section 1	Section 2	Section 3	Section 4
Porosity	20.3%	16.1%	37%	35.6%

anterior and posterior cortices have a relatively constant porosity in all sections. The porosity of the medial cortex increases dramatically from down to up, by a factor of 3.9, suggesting the presence of stress-shielding.

Medullary bone porosity (table VI). The porosity of medullary bone is significantly increased, by a factor of 2, in the proximal sections (37% and 35.6%) as compared with the distal ones (20.3% and 16.1%). The medullary bone is mainly located in the periprosthetic space where the implant is in closest proximity to the cortex. In the other areas, medullary bone formation is nearly evanescent.

A graph (fig. 7) illustrates the overall proximal-to-distal gradients of each of the major quantitative parameters of this observation.

DISCUSSION

Histologic findings indicate that HA-coated titanium alloy provides an osteophilic substrate for bony proliferation, even in areas that did not intially have bone-implant contact (16). In clinical situations, as in elderly osteoporotic patients with hip fractures, the implant fit to the bone is usually not optimal. Gaps of 1-2 mm are found under tibial plateaus of total knee arthroplasties (36) and around hip implants (15). Additionally, grooves 2-3 mm deep are often created at the surface of the implant in order to improve its mechanical retention. These defects have been shown to be filled at a faster rate (31, 34) and in a more effective way (deeper penetration of bone within the grooves) with HA-coated implants (8,35).

Apposition of bone is found to be significantly increased from proximal to distal (1). A similar distribution is also noted with porous-coated femoral stems (10, 11, 14). Bone formation is most prominent in areas of relatively good initial fit, or in areas of anticipated load transfer. These areas are submitted to compressive and shear stresses. The condensed trabeculae adjacent to the corners of this grossly quadrangular implant probably reflect adaptation to torsional stresses. The higher bone-affinity index around the distal third of the stem is presumably related to the presence of HA coating along the whole length of the stem.

The higher rate of coating resorption in the proximal femur has been mentioned previously (23). All implants retrieved at least one year after implantation display some resorption of the HA coating (1, 17, 23, 26). Resorption of HA is a cell-mediated process, where osteoclasts play an important role. The natural ability of these cells to resorb HA coatings is well documented (12) and is confirmed by the presence of HA granular particles within the cytoplasmic compartment. Activation of osteoclasts in the proximal stress-shielded area may account for the higher rate of HA dissolution in this location. This hypothesis still needs confirmation.

The two major concerns with HA degradation are 1) subsequent loosening of the stem and 2) release of HA debris into the joint.

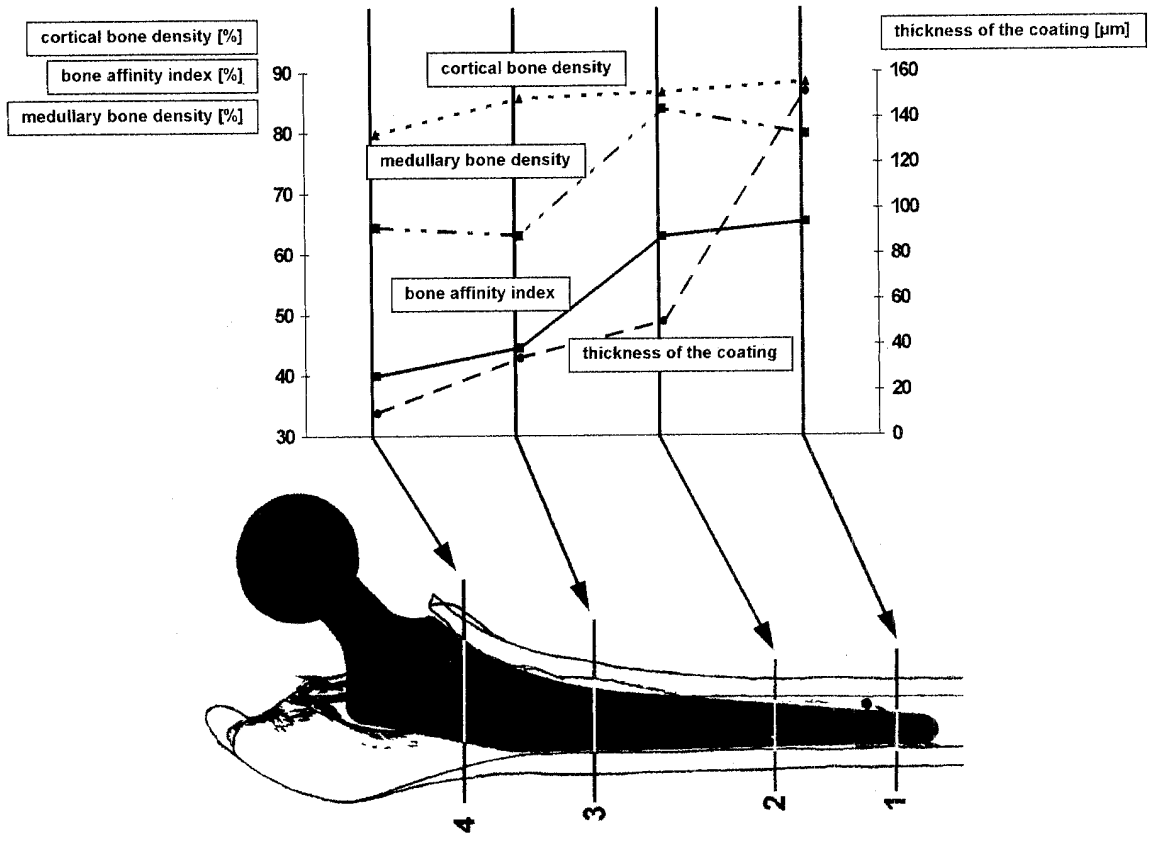

Fig. 7. — The different histomorphometric data according to the level of the section. From up to down, the average thickness of the coating, the average cortical bone density, the average medullary bone porosity and the bone-affinity index increase.

In an experimental model using push-out testing of unloaded transcortical plugs, Klein *et al.* (25) concluded that apatite coatings give rise within the first 3 months to a strong bone bonding which persists for a long time, even after degradation of the apatite coating itself. Their histopathologic findings showed that 80-90% of the coating had disappeared 28 months after implantation, along with incorporation of the coating fragments within the newly formed bone and multiple bone-remodelling lacunae. These findings were similar to ours and support the assumption that degradation of the coating is not equivalent to implant loosening.

Since no interfacial fibrous tissue may be seen, it may be hypothesized that the implant was mechanically well fixed. If the threshold of non-fixation was attained, formation of fibrous tissue would take place at the interface (7, 13).

Concern has been expressed that HA particles could migrate into the joint space and trigger or accelerate polyethylene wear by acting as a third body (2, 4, 27, 28, 29). Masson *et al.* reported on six well-fixed HA-coated RM polyethylene cups retrieved during revision operations performed for femoral loosening (27). Morscher reported on four similar cups revised after 8 to 10 years (29). HA granules were found on the articulating surface of the PE cup, along with scratches on the metallic head and polyethylene wear. Nevertheless, earlier histologic studies of the HA-coated RM cup revealed delamination of the HA coating from the polyethylene surface, which is not the case when the HA coating is applied on a correctly prepared metallic substrate. Our previous observations failed to reveal any occurrence of delamination. Therefore, experience gained with HA-coated polyeth-

ylene cups cannot be transposed to the HA-coated metallic femoral stems.

On another hand, the reports by Bloebaum *et al.* were based upon one (4), then 15 (6) *failed* total hip replacements analyzed after they were explanted during revision surgery. Extensive tissue metallosis was found, along with wear of the polyethylene insert in the superior region, loosening of the 3 screws and presence of several cysts of 4.5 cm × 2.75 cm × 3-4 cm depth in the acetabular bone (4). This means that the implant was totally loose. Subsequent mechanical abrasion of the HA coating did certainly occur, with flaking off of the coating and disseminating of debris within the joint space. This possible scenario with loose implants is quite different from the slow emission of HA articles due to the resorptive processes described here and by others with well-fixed implants. Bloebaum's hypothesis (*osteolysis due to emission of HA debris causing wear of the polyethylene*) is questionable. Primary wear of the polyethylene causing osteolysis, with subsequent fragmentation of the HA coating due to the acquired micromotion of the implant is a possible alternative. Bauer *et al.* (2) reported 4 polyethylene inserts retrieved during revision of failed HA-coated femoral components. They could not document the presence of HA particles embedded in the polyethylene. Examination of the articulation surface of the metallic femoral head was also performed. The roughness of these heads was significantly lower when they came from HA-coated stems as compared with other uncemented or cemented stems. Finally, it should be remembered that the presence of HA crystals in synovial fluids (9,20) and their deposition in the articular cartilage (30) is a common finding. This provides further evidence that one should remain circumspect when interpreting the presence of HA particles in a joint cavity.

The significance of the lucent line appearing in the proximal interface is far from being clear. It is tempting to incriminate the emission of wear debris from the joint surface and the subsequent activation of osteoclasts. However, we could not demonstrate the presence of polyethylene particles that could suggest third-body wear, despite extensive and careful search with the polarized light microscope. The presence of HA particles in this tissue was rare and very often extracellular, making macrophage activation by this kind of debris unlikely (21, 37). Metal debris was found in the mononuclear macrophages forming very small and rare groups of cells disseminated within the collagen bundles. These metal particles were composed by stainless steel particles and titanium alloy particles. The origin of these metallic particles remains unknown. The simultaneous presence of titanium and stainless steel particles is perhaps related to corrosion at the taper. Other origins like the femoral head, as suggested by the presence of metallic particles within the polyethylene insert or the metallic shell of the bipolar head, may also be postulated.

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SAMENVATTING

D. C. R. HARDY, P. FRAYSSINET, P. KRALLIS, P. Y. DESCAMPS, L. FABECK, J. L. DELPLANCKE, P. E. DELINCE. Histopathologie van een goed functionerende hydroxyapatiet gecoate femurprothese na 52 maand.

Een volledig met hydroxyapatiet gecoate femorale implant werd tijdens een autopsie gepreleveerd. De component werd 52 maanden voordien geplaatst bij een femurhalsfractuur. Osteointegratie van de implant was duidelijk, zonder vorming van fibreus weefsel : 39,9% van de omtrek van de prothese thv het proximale 1/3 was geconfronteerd met bot (62,8% thv het middenste derde en 65,2% distaal).
Botremodellage werd nagegaan. Botdepositie was meest evident in de calcar zone, langs de mediale en laterale zijden en aan de tip ; proximaal was de porositeit ca 73% hoger terwijl medullaire bot porositeit toegenomen was met een factor 2.
Cellulair gemedieerde resorptie van de coating was systhematisch aanwezig in de remodellage zones. De gemiddelde dikte van de coating was resp. 10,8, 50,2 en 151,2 micrometers proximaal, midden en distaal. Botvorming was vaak geassocieerd aan resorptie. Er werd geen debris van de coating teruggevonden in de gewrichtsweefsels noch in het articulerende oppervlak van de polyethyleen insert.
Deze bevindingen ondersteunen de mechanische stabiliteit van de implant en de actieve remodellage van het bot semen met een systhematische resorptie van de hydroxyapatiet coating. Er werden geen neveneffecten van de coating degradatie geobserveerd.

RÉSUMÉ

D. C. R HARDY, P. FRAYSSINET, P. KRALLIS, P. Y. DESCAMPS, L. FABECK, J. L. DELPLANCKE, P. E. DELINCE. Étude histopathologigue d'un implant fémoral à revêtement d'hydroxyapatite explanté après 52 mois.

Les auteurs présentent les résultats de l'étude histopathologique d'un implant fémoral à recouvrement complet d'hydroxyapatite, explanté à l'occasion d'une autopsie. Cet implant, dont la tête était associée à une cupule mobile, avait été mis en place pour une fracture déplacée du col fémoral 52 mois auparavant.
L'ostéointégration de l'implant était évidente, sans formation de tissu fibreux : 39,9 % du périmètre de la prothèse au niveau de son tiers proximal était en contact avec de l'os (62,8% au tiers moyen et 65,2% au tiers inférieur). Un remodelage osseux s'était produit. La néoformation osseuse était surtout importante dans la zone du calcar, le long des faces médiale et latérale et autour de la pointe de la tige. A la partie proximale, la porosité corticale était augmentée de 73%, tandis que la porosité de l'os spongieux était doublée.
Une résorption du revêtement d'hydroxyapatite par un processus cellulaire était systématiquement présent dans ces zones de remodelage osseux. L'épaisseur moyenne du revêtement était respectivement de 10,8, 50,2 et 151,2 µm au tiers proximal de l'implant, au tiers moyen et au tiers distal. La néoformation osseuse était souvent couplée à une résorption. Les auteurs n'ont pas trouvé de débris de revêtement dans les tissus articulaires, ni dans la surface articulaire de l'insert en polyéthylène. Ces caractéristiques histopathologiques plaident dans l'ensemble pour une stabilité mécanique de l'implant et un remodelage osseux qui vont de pair avec la disparition focale du revêtement d'hydroxyapatite, associée à une activité ostéoclasique. Les auteurs n'ont pas observé d'effets secondaires liés à la dégradation du revêtement.