Arch Orthop Trauma Surg (2000) 120 : 160–165

ORIGINAL ARTICLE

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Experimental study of bone-implant contact with a parabolic acetabular component (Hofer-Imhof)

Received: 10 February 1999

Abstract Incomplete bone contact with threaded acetabular components is usually attributable to the tapered thread design and sclerotic bone, and might be the reason for early loosening. The self-tapping flat threads of the Hofer-Imhof cup allow accurate insertion without incarceration, even in sclerotic bone. To demonstrate the effectiveness of this threaded cup design based on digitized measurements of bone contact area, six Hofer-Imhof cups were implanted into three human cadavers. The bone contact area at the threads was digitally analyzed on cadaver-explanted cups cut into horizontal and coronal sections. In cups fixed with ideal form fit, bone contact was 31.6% (range 8–55%) at the threads and 28.5% (range 0–49%) between the threads on average. In cups with incomplete bone contact secondary to insufficient reaming, the bone contact area averaged 27.4% (range 10–44%) at the threads. In sclerotic bone, the highest bone contact at the threads was 69%. The threads were the first part of the cup to achieve primary bone contact. Factors contributing to poor contact were incomplete reaming, sections which passed through the incisura of the acetabulum, and incomplete contact with the medial aspect of the acetabulum. The aim was to achieve complete bone contact. Because of the higher contact areas observed in sclerotic bone, some sclerotic bone should remain after reaming.

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Introduction

Recent reports indicate a high mid-term failure rate for smooth, hemispherical, threaded cups [6, 7, 15]. However, the final outcome for threaded cups is dependent on both material and design.

A significant step forward in threaded cup design was made when innovative corundum-blasted titanium structures came into use in the middle of the Eighties. Threaded titanium cups with a surface irregularity of 3–5 µm can be as successful as cementless press-fit or cemented polyethylene cups over the mid-term [3, 5].

During the insertion of cups with tapered threads, the implant can become jammed before the desired position is achieved. In the case of sclerotic bone located superiorly and cancellous bone inferiorly, the cup may shift more towards the inferior bone [3, 12–14]. In both cases there will be incomplete bone-implant contact, which might lead to early revision. Incomplete bone contact can be identified with anteroposterior (AP) pelvic radiographs, especially with a 20° caudal view [4, 5]. The orthopedic surgeon aims to ensure initial bone contact to promote ingrowth at the earliest possible stage. Not only cup position, but cup design is also crucial in achieving the goal of initial bony stability. However, to date, only a few anatomical studies have examined or compared mid-term radiographic findings based on criteria such as initial bone contact, cup position, effects of reaming, fixation on osteophytes, uncovered threads, radiolucencies, implantation in sclerotic versus cancellous bone, cup migration, bone ongrowth and revision rates [9].

To obtain such findings, we selected the Hofer-Imhof cup which is designed with flat, self-tapping threads to avoid the problems of insertion, jamming and positioning [4]. This cup not only allows accurate insertion without incarceration, and even in sclerotic bone, the 3- to 5-µm surface irregularity promotes bone ingrowth [1, 9].

In a prospective study conducted from May 1988 to July 1989, 119 of 143 implanted Hofer-Imhof cups were radiographically evaluated after a mean implantation time of 65 months (min. 37 months, max. 86 months). This study showed that 82.4% of the Hofer-Imhof cups with flat, self-cutting threads had complete bone ingrowth without any evidence of radiolucency (type I); 15.1% had near-complete bone ingrowth with minimal radiolucency (type II) and 2.5% had predominantly fibrous fixation (type III). Overall, 86.6% of the cups showed complete bone contact on the postoperative X-ray. Stability or osseointegration were not influenced if there was only one uncovered thread at the rim. One case with two uncovered threads showed radiolucencies in two-thirds of the cup but no migration; this case was not revised because the patient showed no clinical symptoms.

The combined clinical and pathological study reported here was conducted to further evaluate the merits of this cup design based on digitized measurements of bone contact area.

Materials and methods

For this interdisciplinary approach, six Hofer-Imhof cups were implanted into the hips of three cadavers (two female, one male, mean age at death 75 years) who had not died of bone or hip-related illnesses. The Hofer-Imhof cup consists of a parabola-shaped titanium acetabular component. Its self-cutting flat threads (Fig. 1) allow more accurate insertion than tapered threads. The cup has a 3- to 5-µm surface irregularity which promotes bone ingrowth.

All dissections were performed through an anterolateral approach. Sequential reaming served to restore the conical fossa required for placement of the threaded cup. The cartilage was removed before reaming. Component fixation was assessed to be stable when further attempts to screw in the cup resulted in pelvic raising.

After removal, the bone-implant block was fixed in 7.5% buffered formalin and radiographs were taken in two planes. The block was then sectioned into horizontal and coronal slices (Fig. 2) on a high-speed low feed band saw (Exakt-Apparatebau Hermann, Norderstedt, Germany). The slices were then embedded in methyl methacrylate. Sections, 100 µm thick, were cut and ground from the blocks and microradiographs were taken. Further grinding was performed down to about 10-µm thickness and the sections were polished on a PM2 polisher (Logitech, Glasgow, UK). Staining was done with toluidine blue.

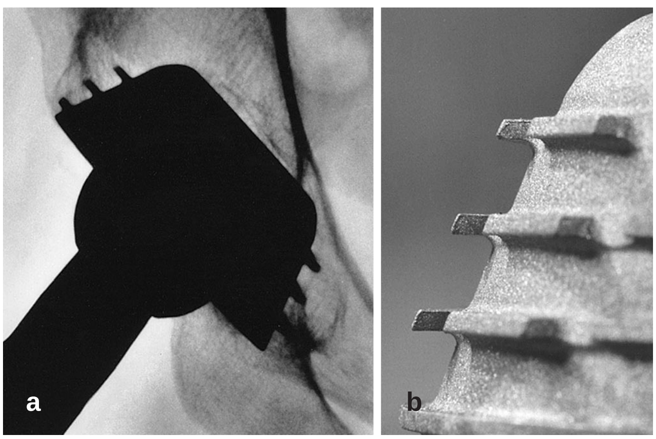


Fig. 1 **a** Parabola-shaped threaded cup (Hofer-Imhof); 20° inclined AP radiograph for better demonstration of bone contact and flat threaded design (45-year-old female). **b** Flat thread design (*AP* anteroposterior)

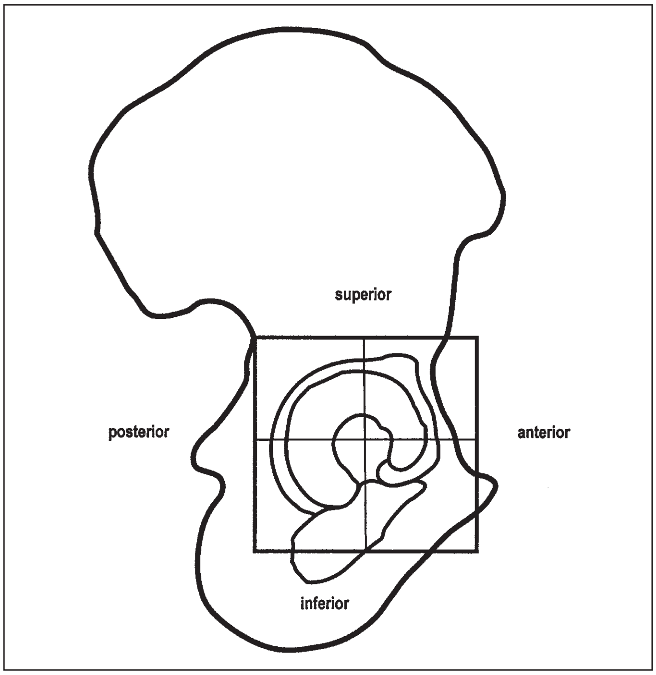


Fig. 2 Horizontal and coronal planes of the acetabulum

Table 1 Bone contact at the threads (in %) ++ only two threads for measurements, +++ only three threads for measurements

	Case 1		Case 2		Case 3	
Posterior	Right	Left	Right	Left[a]	Right[b]	Left
1	0	–[c]	–[c]	12	38	21
2	13	49	34	7	0	29
3	23	69	32	7	8	12
4	+++	35	++	+++	+++	0
Anterior						
1	0	30	42	12	–[c]	49
2	0	55	29	21	30	5
3	0	26	8	30	18	11
Superior						
1	0	62	44	0	0	60
2	33	50	17	23	0	18
3	11	13	10	30	0	9
Inferior						
1	0	57	0	0	0	–[c]
2	0	31	0	9	0	0
3	0	32	0	20	0	20
4	+++	+++	26	+++	+++	19

[a] Shown in Figs. 3–5
[b] Shown in Figs. 6–8
[c] Incomplete threads at the rim of the acetabular component which are not included in the measurements

Image analysis

The bone contact area at the threads and between the threads was measured separately using an image analysis system (Lucia D,

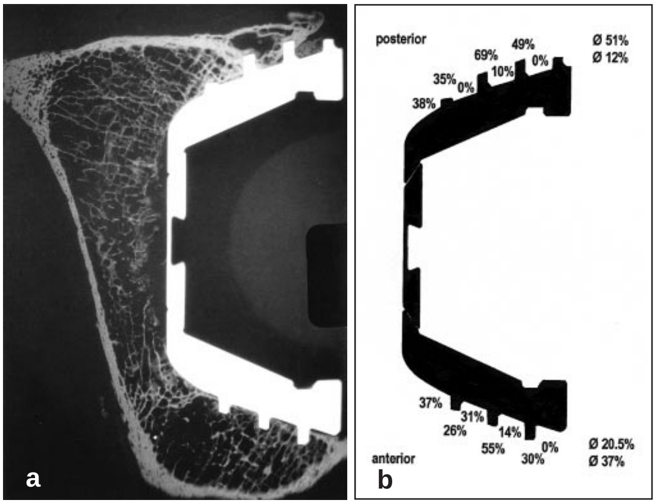


Fig. 3 a, b Case 1, left hip of an 80-year-old female. **a** Micrograph, horizontal section. **b** Bone contact

Nikon, Austria). Bone-implant contact index (BICI) [2] is defined as the area of implant at the threads and between the threads directly opposed to bone. This technique was initially designed for bone contact measurements in cementless stems [2, 10]. Measurements were only taken where the cup was in contact with the bone. Threads at the margin of the cup and without full depth were not included in the measurements (Table 1).

Results

Autopsy results of two individual cadavers with typical radiographic findings are shown below.

Case 1

Case 1 was a female, 80 years old. The left hip represents an example of good bone contact. The horizontal microradiograph section (Fig. 3 a shows that the threads in the posterior part were mainly anchored in the subchondral sclerotic bone. The last thread at the margin of the cup was free. The bone-implant contact for the threads fixed in sclerotic bone ranged from 35% to 69% (Fig. 3 b), mean 51%. Anteriorly, all the threads were completely covered with bone and ideal form fit was achieved. The threads fixed in cancellous bone had an average bone-implant contact of 37% (range 26–55%). The bone-implant contact between the threads averaged 20.5% (range 0–37%).

The AP radiograph (Fig. 4 a) showed good bone contact in the superior and inferior planes and only the superior margin was free. Corresponding to the radiograph in Fig. 4 a, the microradiograph showing the superior aspect revealed an exposed thread (Fig. 4 b) and compressed cancellous bone between the threads. Because the remaining threads were fixed in sclerotic bone, the average bone-implant contact was 41.6% (range 13–62%, Fig. 4 c). There was no bone-implant contact between the threads resulting from a small gap of a few micrometers, which is not seen in the radiograph.

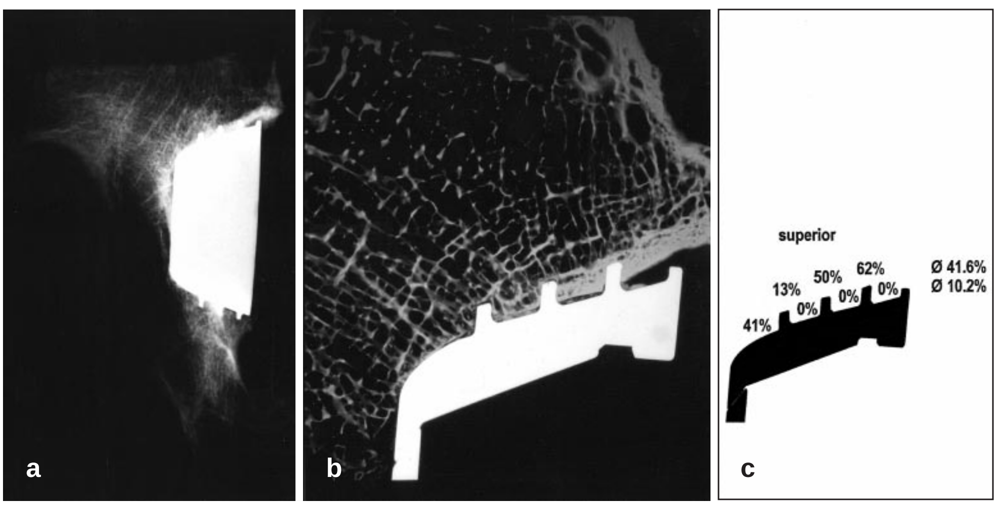
The inferior part of the X-ray (Fig. 4 a) shows complete bone contact, but the microradiograph of the same section (Fig. 5 a) reveals that this area is close to the incisura of the acetabulum, exposing one and a half threads. Since the other threads were fixed in sclerotic bone, the bone contact area achieved at the threads was 40%. Bone-implant contact between the threads averaged 4.6% (Fig. 5 b).

Case 2

Case 2 was a female, 73 years old. The right hip of this case represents incomplete bone contact. The horizontal microradiograph section (Fig. 6 a) shows a gap in the posterior plane resulting from incomplete reaming. Thus, the threads were not completely fixed in the bone, with the most lateral thread remaining uncovered and the other two only partially fixed. Because fixation was mostly performed in sclerotic bone, an average bone-implant contact of 33% (range 32–34%) was achieved at the threads and 11.6% (range 0–35%) between the threads (Fig. 6 b).

There was complete form fit in the anterior aspect, with fixation in sclerotic bone at the rim and cancellous

Fig. 4 a–c Case 1, left hip. **a** AP radiograph. **b** Micrograph, superior section. **c** Bone contact



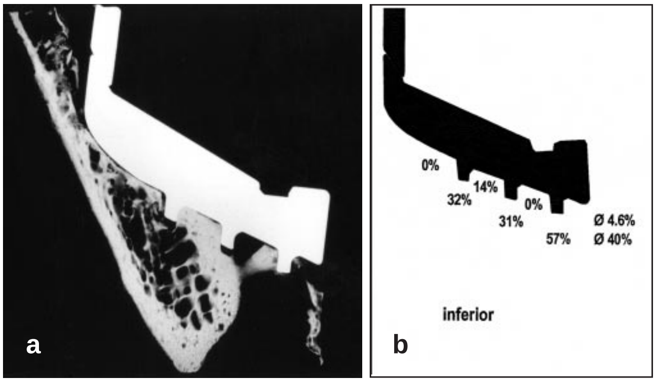


Fig. 5 a, b Case 1, left hip. **a** Micrograph, inferior section. **b** Bone contact

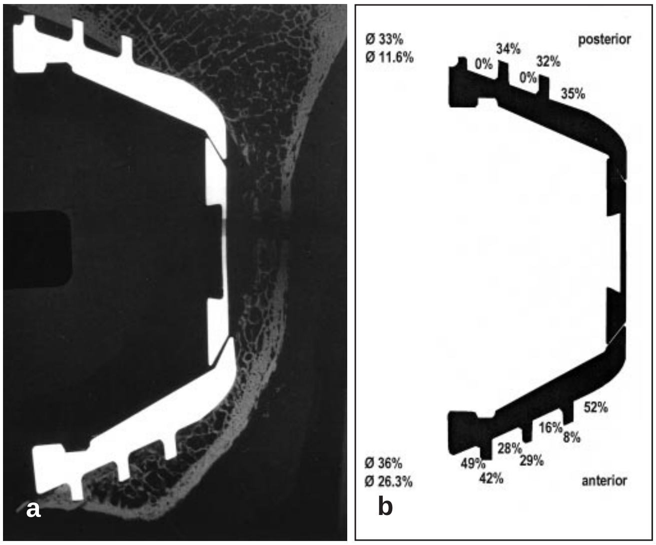


Fig. 6 a, b Case 2, right hip of a 73-year-old female. **a** Micrograph, horizontal section. **b** Bone contact

bone close to the bottom of the acetabular component. A bone-implant contact of 26.3% (range 8–42%) at the threads and of 36% between the threads was measured.

On the superior and inferior parts of the AP radiograph (Fig. 7 a), the cup appears to have good bone contact in all areas with a sclerotic line visible in the superior part. The microradiograph (Fig. 7 b) shows that the sclerotic line forms the borderline of a 2-mm gap. The appearence of cancellous bone on the radiograph between the implant and the sclerotic line is produced by the accumulative effect of the AP view. The superior part of the microradiograph (Fig. 7 b) shows an average bone-implant contact of only 23.6% at the threads (Fig. 7 c). An average bone-implant contact of 1.6% (range 0–5%) between the threads was found in the case of fragmented bone, resulting from screwing in the acetabular component.

In the inferior section (Fig. 8), only the thread near the bottom of the acetabular component showed bone-implant contact with an average bone contact of 8.6% at the threads. Fragmented cancellous bone between the threads increased bone contact which was 29% on average (range 14–58%). All data are compiled in Tables 1 and 2.

If the implant had ideal form fit, on average a bone contact of 31.6% was reached at the threads (min. 8%, max. 55%). The bone-implant contact area between the threads was 28.5% on average (Figs. 3, 6; anterior section). If there was incomplete form fit, due to incomplete reaming, the highest bone-implant contact at the threads was 44%, because of fixation in sclerotic bone. The bone contact area averaged 27.4% (range 10–44%) at the threads and 6.6% between the threads (Fig. 6, posterior section; Fig. 7, superior section).

Factors which reduced the bone contact area were: incomplete contact due to incomplete reaming (Fig. 6, posterior section), a small gap (Fig. 4 b) of several micrometers, which arose despite adequate bone contact (Fig. 4 b, c), and an inferior cut close to the incisura of the acetabulum (Figs. 5, 8).

Fragmented bone, resulting from screwing in the cup increases the bone contact (Figs. 7, 8) between the threads, where there would otherwise be no bone contact. The cup was never in complete contact with the medial aspect of the acetabulum (Figs. 3, 6).

Discussion

We aimed to demonstrate the effectiveness of the Hofer-Imhof threaded cup design based on digitized measurements of the BICI [2, 10].

The reamers and the cup are parabola shaped which is in contrast to the hemispheric anatomic acetabulum. There-

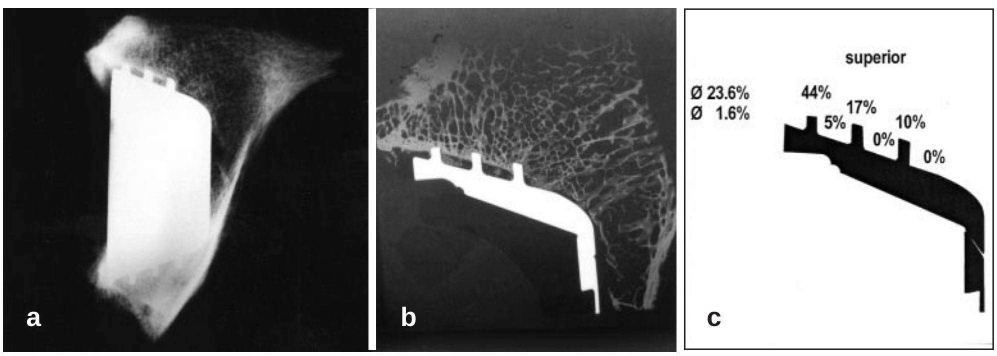


Fig. 7 a–c Case 2, right hip. **a** AP radiograph. **b** Micrograph, superior section. **c** Bone contact

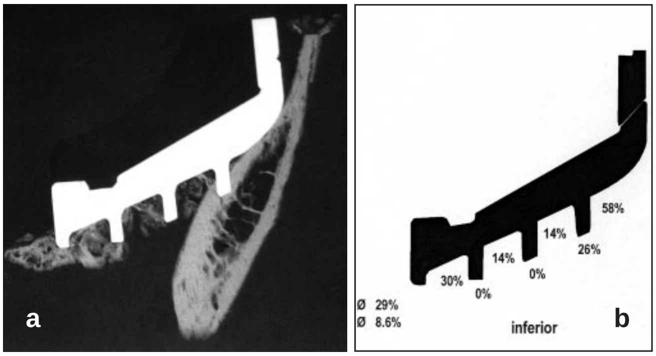


Fig. 8 a, b Case 2, right hip. **a** Micrograph, inferior section. **b** Bone contact

Table 2 Bone contact area between the threads (in %) (+++ only three areas of contact used for measurements)

	Case 1		Case 2		Case 3	
Posterior	Right	Left	Right	Left[a]	Right[b]	Left
1	0	0	0	0	–[c]	0
2	0	10	0	0	0	0
3	0	0	35	0	0	46
4	+++	38	+++	+++	0	0
Anterior						
1	0	0	49	–[c]	0	0
2	0	14	28	62	0	0
3	24	31	16	71	3	0
4	31	37	52	0	+++	0
Superior						
1	7	0	0	–[c]	0	5
2	0	0	5	0	0	0
3	0	0	0	0	0	0
4	+++	41	0	5	0	4
Inferior						
1	0	0	30	0	0	0
2	0	14	14	0	0	0
3	0	0	14	16	0	12
4	0	0	58	17	0	0

[a] Shown in Figs. 3–5
[b] Shown in Figs. 6–8
[c] Small area of the acetabular component at the rim which are not included in the measurements

fore, since sclerotic bone is left virtually untouched at the rim but removed medially, a low bone contact is achieved medially and higher bone contact at the rim. Because the density of cortical bone is higher than that of cancellous bone we have a greater bone contact in sclerotic bone and a lower bone contact in cancellous bone. The two most lateral threads were usually were fixed in sclerotic bone, but sometimes with incomplete bone contact. Incomplete bone contact at the rim was caused by incomplete reaming intended to protect sclerotic bone and not by incarceration of the threads. It is felt that retaining sclerotic bone is beneficial to load transfer, because the subchondral bone within the acetabulum transmits a major part of the load bearing in the form of membrane stresses from the hip joint to the rim and then onto the cortical shell of the ilium [8]. Nevertheless, incomplete bone contact in sclerotic bone gives the same contact area as complete bone contact in cancellous bone.

Another reason that bone-implant contact was incomplete was that the inferior cut was close to the acetabular incisura. Thus, while the most medial threads were usually completely fixed in cancellous bone, in the inferior portion where there was no bone-implant contact. Hence, cancellous bone grafting to the incisura of the acetabulum after reaming and before implantation might increase bone contact between the threads.

The highest bone contact was 69% for threads in sclerotic bone (Fig. 3). In cups fixed with ideal form fit, bone contact was 31.6% (range 8–55%) at the threads and 28.5% (range 0–49%) on average between the threads, which seem to be the highest achievable contact rates. Lintner et al. [11] specify 27% for good implanation, whereas osseointegrated cups have 55% after 14 months. Bone removed from the acetabulum by the threads during the screwing in of the cup was trapped between the threads and produced additional bone contact in areas where there would otherwise be no contact. This side effect is essential for osseointegration at the earliest possible stage [11].

The cups were never in complete contact with the medial aspect of the acetabulum because the reamers are constructed to be deeper than the acetabular component to ensure that the bottom of the acetabular component has contact with the bottom of the acetabulum. Only when the acetabular component compresses the bone of the acetabulum can the top of the acetabulum be reached. This might be a situation where there is predominately cancellous bone or thin cortical bone.

Incomplete bone contact which can be demonstrated with microradiography is not always seen radiographically. For example, the sclerotic line on the radiograph shown in Fig. 7 is an indirect sign of incomplete bone contact. This line represents the borderline of the acetabulum. Although there is complete contact shown on the radiograph, the bone contact is incomplete because the bone seen between the threads results from a summation of the AP radiographic view. The threads had high bone-implant contact in the sclerotic bone, while there was lower contact in the cancellous bone. The bone-implant contact at the threads is twice as high as the bone contact area between the threads.

Because of the higher contact areas observed in sclerotic bone, we believe that some sclerotic bone should remain after reaming. To obtain an optimal bone contact, there should be no uncovered threads. This initial bone contact is sufficient to achieve good mid-term radiological results.

References

1. Albrektsson T, Branemark PI, Hansson HA, Lindström J (1981) Osseointegrated titanium implants. Requirements for ensuring a long-lasting, direct bone-to-implant anchorage in man. Acta Orthop Scand 52 : 155–170
2. Böhm G, Lintner F, Klimann S, Huber M (1995) Histomorphologic and morphometric evaluation of cementless implanted hip endoprotheses. Int J Surg Pathol 2 [Suppl] : 9
3. Delaunay C, Kapandji AI (1997) Acetabular screw rings and surface treatment. Clin Orthop 340 : 130–141
4. Effenberger H, Hofer H (1991) Concepts and experience with the Hofer cup. In: Küsswetter W (ed) Noncemented total hip replacement. International Symposium, Tübingen 1990. Thieme, Stuttgart, pp 275–280
5. Effenberger H, Krok E, Ramsauer Th, Harich B (1997) Threaded cup design yields success in primary hip arthroplasty. Orthop Trans 21 : 223
6. Engh CA, Griffin WL, Marx CL (1990) Cementless acetabular components. J Bone Joint Surg Br 72 : 53–59
7. Hernandez-Vaquero D, Suárez-Vazquez A, Fernandez-Corona C, Menandez-Vinuela G, Alegre-Mateo R, García-Sandoval A (1996) Loosening of threaded acetabular cups in arthroplasty of the hip – The association with different types of coxarthrosis. Int Orthop 20 : 70–74
8. Jacob HAC, Huggler AH, Dietschi C, Schreiber A (1976) Mechanical function of subchondral bone as experimentally determined on the acetabulum of the human pelvis. J Biomech 9 : 625–627
9. Lintner F, Zweymüller K, Brand G (1986) Tissue reaction to titanium endoprostheses, autopsy studies in four cases. J Arthroplasty 1 : 183–195
10. Lintner F, Böhm G, Huber M, Scholz R (1994) Histology of tissue adjacent to an HAC-coated femoral prosthesis. J Bone Joint Surg Br 76B : 824–830
11. Lintner F, Böhm G, Huber M (1994) Zementreie Schraubpfannen – Morphologische, mikroradiographische und morphometrische Untersuchungen zum Einbauverhalten. Med Orthop Techn 114 : 233–237
12. Shaw JA, Baily JH, Bruno A, Greer RB (1990) Threaded acetabular components for primary and revision total hip arthroplasty. J Arthroplasty 5 : 201–216
13. Snorrason F, Kärrolm J (1990) Primary migration of fully-threaded acetabular prostheses. J Bone Joint Surg [Br] 72 : 647–652
14. Tallroth K, Slätis P, Ylinen P, Paavolinen P, Paavilainen T (1993) Loosening of threaded acetabular components. Radiographic manifestations. J Arthroplasty 8 : 581–584
15. Yahiro AM, Gantenberg JB, Nelson R, Lu HTC, Mishra NK (1995) Comparison of the results of cemented, porous-ingrowth, and threaded acetabular cup fixation – A meta-analysis of the orthopaedic literature. J Arthroplasty 10 : 339–350