Modes of failure of a threaded acetabular cup

A radiographic study with EBRA of 42 revised cups

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Abstract A radiographic study of a singular type of threaded cup, revised due to aseptic loosening, was performed with Einzel-Bild-Roentgen-Analyse (EBRA) to detect eventual risk factors and patterns of loosening. Fifty-three cups of 50 patients were revised. Forty-two cups could be measured with EBRA. No cup had obvious osteolysis, 33 cups demonstrated early migration, and all cups had migrated at the time of revision. Twenty-eight of the cups had a change of inclination and 21 of anteversion, respectively. The mean migration was 1.9 mm in the medial and 7.9 mm in the cranial direction; the mean wear rate was 0.2 mm/year. Cups with early migration had a higher migration rate. All male patients had early migration; medially placed cups had less migration than the other cups. Wear was not significantly affected by the migration of the implant. No cup had a complete radiolucent line, and the only radiographic sign for loosening was the change of position of the cup. Medial placement showed less migration in case of loosening. Regular radiographic follow-up is recommended for the examined implant, and the cup should not be used in the future.

Résumé Une étude radiographique d'une cupule vissée reprise pour descellement aseptique a été faite avec la méthode EBRA pour détecter les facteurs du descellement. Cinquante-trois cupules chez 50 patients étaient révisés; 42 avaient les mesures EBRA. Dans aucun cas il n'y avait d'ostéolyse évidente. Toutes les cupules avaient migré au moment de la révision et de façon précoce pour 33 d'entre elles. La migration moyenne était de 1,9 mm en dedans et de 7,9 mm vers le haut. Vingt-huit cupules avaient un changement d'inclinaison et 21 d'anteversion. L'usure moyenne était de 0,2 mm par an. La migration finale était plus importante pour les cupules ayant migré précocement. Tous les patients masculins avaient une migration précoce. L'usure n'était pas affectée par la migration. Aucune cupule n'avait de liseré complet et le seul signe de descellement était le changement de position de la cupule. La situation médiale de la cupule semble plus stable avec moins de migration en cas de descellement. Cette cupule ne doit plus être utilisée.

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Introduction

Threaded cups are available with spherical and conical shapes, various numbers and types of threads and coatings. For some threaded cups, good to excellent results have been reported [5]; others had a poor early to mid-term outcome and are no longer recommended [6].

Little is known about the modes of failure of threaded cups. Snorrason and Kärrholm [23] studied 20 cups with radiostereometry (RSA) and found significant initial migration in all cases. High peak forces on the threads might lead to stress-induced osteonecrosis [7]. Malplacement or malorientation of the cups might lead to a poor contact between the prostheses and bone [22]. The quality, distance and

depth of the threads might affect the initial stability [13], and the quality of the surface affects the ingrowth [20].

We were using a threaded cup from 1987 to 1998 in about 1,500 patients with a modification of the surface of the cup and the bottom of the inlay in 1990 and have observed an increasing number of aseptic loosening [25]. Use of the threaded cup was abandoned in 1998; a spherical press-fit cup was used instead. Fifty-three threaded cups in 50 patients were revised at our hospital for aseptic loosening from the year 1994 to 2000. Over the same period of time, about 250 cup revisions of various designs have been performed.

The aim of the study was the analysis of patterns of migration and also malpositioning, malorientation, migration and wear for a singular threaded cup that subsequently went to loosening. An accurate analysis of migration, wear and cup orientation was made with the EBRA method. The measurement accuracy of EBRA has been assessed in previous studies [1, 8, 15] for cemented spherical cups below 1 mm for migration (95% confidence). Kordelle and Starker [14] studied the threaded Zweymueller socket with EBRA and postulated an error of measurement below 1 mm.

Patients and methods

With the EBRA method, 42 of the 53 revised cups could be analysed in the horizontal and vertical direction. Eleven cups were excluded by the software because of projection differences of the radiographs exceeding the tolerance limit of the method, which might have compromised the measurement accuracy. The initial diagnosis of the analysed cups was primary osteoarthritis in 28, posttraumatic arthrosis in 3, dysplasia in 7 and other diagnoses in 4 hips. Four hips had undergone previous surgery, and one threaded cup was used as a revision implant.

The mean age at the primary operation was 58 (29 to 78) years; 26 patients (28 hips) were male. The decision for revision was made in response to complaints of the patients or obvious migration with consecutive loss of bone and was independent of the study.

The threaded cup examined ("Muenchen", Aesculap, Tuttlingen) was made of titanium with a spherical outer shape. The original surface was smooth until 1990. About 200 cups of this type were implanted, and 19 of them were revised and included in the study. As of 1990, the implant was modified: the surface was roughened and the base of the inlay was covered with a titanium-layer to avoid direct contact between the polyethylene and bone in the bottom of the cup. Twenty-three of the cups we measured belonged to the modified system. All inlays were made of the same polyethylene, which was partially cross-linked and gamma sterilised in inert gas (Chirulen GUR 1020 UHMWPE).

All patients had a cementless stem (BiContact, Aesculap, Tuttlingen) and a 32-mm metal head. No stem had been revised or had signs of loosening before or during cup revision.

The primary operations were performed or supervised by consultants, and 31 operations were done by surgeons with a special interest in hip surgery. Overall, 12 different surgeons were involved.

All but five patients had a central bone grafting to improve the central ingrowth of the implant. Six patients had cranial bone grafting, three of them a solid graft with screw fixation. Cranial bone grafting was performed for severe dysplasia in one case, and protrusion, posttraumatic and other acetabular deficiencies in the remaining cases.

The preferred implant position was to have the same centre of rotation, as compared to the healthy contralateral hip. It was determined on the preoperative radiographs and compared with the postoperative implant position by using the Nunn lines as reference lines [8]. In bilateral hip disease, the method of Ranawat et al. [21] was used. On the postoperative radiograph, eventual central gaps between the bottom of the cup and the acetabular bone were noted; the lateral bone-implant contact was recorded by counting the number of eventual uncovered threads.

All postoperative radiographs were measured for migration, wear, change of inclination and anteversion with the EBRA method [1, 15]. The point of measured translation of the cup was the centre of a circle that was approximated to its outer contour. All measurements were performed by one person (SN).

In total, 370 postoperative pelvis radiographs (mean 7; range 4 to 13 per patient) were analysed.

Data was stored on a PC. The Mann-Whitney U-test, Fisher's exact test and linear regression analysis were performed as statistical tests. A t-test was not performed because of an abnormal distribution of the data. Multiple linear regression confirmed the presented statistical data, but could not add further information because of the low number of cases.

Results

The mean time to revision was 7.2 (2 to 12) years. All implants were found to be loose intraoperatively and were easy to remove. Sometimes, there was obvious migration, but we did not find obvious debonding of the implant from the surrounding bone, osteolytic zones or cysts in any of the cups. The bone loss mainly corresponded to defects caused by the migration of the implant.

From the 42 studied cups, 302 radiographs were analysed and 18 could not be used for any EBRA measurements. All but six measurements started on the postoperative radiograph; for two cups, the first measurement began later than 6 months postoperatively.

Fig. 1 Migration measurements of all implants after 2 years: 9 of the 42 implants (21%) had no detectable migration at 2 years (*open squares*). The two cups with the maximal migration (13.7 and 16.8 mm) were both revised after 2 years. They were placed in a voluminous central bone graft, and for both cases the implanted cup seemed too small, thus probably impairing the grip of the threads

Fig. 2 Migration measurements of all 42 implants before revision after a mean of 7.2 (2 to 12) years. The 33 cups with detectable migration at 2 years (*filled squares*) had more migration (mean 10.1, 1.6 to 21.2 mm) than the 9 cups without detectable migration at 2 years (*open squares*, mean 4.2, 1.1 to 8.4 mm). Twenty-seven of the 42 cups (64%) had migrated in the cranio-medial direction

Thirty-three of the 42 cups (79%) had detectable migration (more than 1 mm) within the first 2 years, and all 42 cups had detectable migration at 5 years (Figs. 1 and 2). In the medial direction, the mean migration was 1.9 (−2.5 to 8.2, SD 3.0) mm and in the cranial direction 7.9 (−1.1 to 21.1, SD 6.0) mm, respectively. For two implants, a caudal migration of −1.1 and −0.7 mm was observed. The mean total migration was 8.8 (1.1 to 21.2, SD 5.8) mm (Table 1, Fig. 2). Cups with early migration had more total migration and a higher migration rate than the other cups (Table 1). The mean direction of migration was 78° (SD 39°) in the cranio-medial direction (Fig. 2).

Twenty-eight of 42 cups (67%) had a detectable change of inclination (more than 3 degrees) and 21 (50%) of anteversion; the mean change of inclination was 4° (−28° to 27°, SD 9.6°) and of anteversion −2° (−8° to 19°, SD 4.8°), respectively. Within the first 2 years, 13 cups (31%) had a detectable change of inclination and 8 (19%) of anteversion, respectively. All cups with early change of inclination and all but one cup with early change of anteversion showed early migration too. There was no correlation of the change of inclination or anteversion and migration.

In 23 of 42 cups (55%), the migration was almost linear (example in Figs. 3, 4), 6 (14%) cups had an early onset and a decrease of the migration with time, for 8 cups (19%) there was an increasing migration with time, and 5 (12%) had a late onset and progressive migration. In no case did cup migration stop in a stable situation.

Thirty-three of 42 hips (81%) had detectable wear (more than 0.5 mm). The mean linear wear was 1.0 (0 to 5.4, SD 0.85) mm, and the mean wear rate 0.2 (0 to 1.0, SD 0.20) mm/year (Table 2). The mean direction of wear was 78° (SD 58°) in the cranio-medial direction.

On average, the cups were placed 0.7 (−10 to 8, SD 4.7) mm medially and 1.4 (−13 to 34, SD 7.9) mm cranially as compared to the ideal position, determined on the preoperative radiograph. For two cups, three lateral threads were not covered with bone, for seven cups two and for four cups one, respectively. The mean inclination was 45° (29° to 63°), and the mean anteversion 10° (4° to 17°). Cups with an inclination below 40° had more uncovered threads ($P=0.004$, significant); no cup with an inclination of more than 50° had uncovered threads. The inclination did not affect the direction ($r^2=0.03$, n.s.) or the amount of migration ($r^2=0.0002$, n.s.) and wear ($r^2=0.069$, n.s.). Eight

Table 1 Mean migration, incidence of early migration and migration rate for all patients and subgroups of patients

Subgroups	Mean total migration mm (min - max, SD)	Significant (Mann-W)	Early migration (n, %)	Significant (Fisher's)	Mean migration rate mm/year (min - max, SD)	Significant (Mann-W)
All (n=42)	8.8 (1.1–21.2; 5.8)	/	33 (79%)	/	1.70 (0.16–9.62; 1.66)	/
Male (n=22)	10.4 (1.6–21.2; 5.8)	0.062	22 (100%)	0.0004*	2.03 (0.28–9.62; 1.87)	0.042
>60 years (n=19)	9.7 (1.3–19.8; 5.6)	0.41	15 (79%)	0.97	2.12 (0.25–9.62; 2.16)	0.22
Medially placed (n=8)	5.6 (1.6–9.5; 2.9)	0.12	3 (38%)	0.006*	0.90 (0.34–1.76; 0.49)	0.021
Laterally placed (n=14)	10.1 (1.1–19.8; 6.5)	0.47	10 (71%)	1.0	2.08 (0.16–9.62; 2.23)	0.34
Central gap >5 mm (n=24)	10.7 (1.1–21.2; 5.7)	0.013*	21 (88%)	0.10	2.17 (0.16–9.62; 1.96)	0.022
Central gap and laterally placed (n=9)	12.2 (1.1–19.8; 6.5)	0.12	8 (89%)	0.39	2.75 (0.16–9.62; 2.53)	0.014*
Early migration (n=33)	10.1 (1.6–21.2; 5.8)	0.0046*	/	/	2.00 (0.28–9.62; 1.72)	0.0002*
Smooth surface (n=19)	9.25 (1.6–19.8; 6.0)	0.49	17 (90%)	0.12	1.39 (0.41–2.39; 0.55)	0.78
Significant wear (n=33)	8.6 (1.1–21.2; 5.8)	1	24 (73%)	0.095	1.78 (0.16–9.62; 1.84)	0.97

For the Mann-Whitney U-test and Fisher's test, significant results are marked (*)

of the 42 cups (19%) were placed more than 3 mm medially to the determined ideal centre of rotation. They had a lower inclination ($P=0.017$, significant) and anteversion ($P=0.054$, n.s.), less migration at 2 years ($P=0.0026$, significant) and a lower migration rate ($P=0.021$, n.s.) than the other implants (Table 1). Fourteen of the 42 cups (33%) were placed more than 3 mm laterally to the determined ideal centre of rotation. These cups had a more cranial direction of migration (mean 86° , SD 36°) than medially placed cups (mean 66° , SD 33° , $P=0.22$, n.s.) but did not differ in the patterns of migration (Table 1).

Twenty-four of the 42 cups (57%) had a lack of contact with the bone of the reamed acetabulum with a central gap of more than 5 mm. They had more migration at 2 years ($P=0.058$, n.s.), a higher total migration ($P=0.013$, sign.) and a higher migration rate ($P=0.022$, n.s.) than the other

cups. The highest migration rate was found for the nine cups with lateral placement and a central gap (Table 1). Position and orientation were not related to the diagnosis, kind of implant, bone graft or experience of the surgeon.

All male patients had early migration. They had more migration at 2 years ($P=0.021$, n.s.) and a higher migration rate ($P=0.054$, n.s.) (Table 1). They did not differ in the wear patterns (Table 2). The age of the patients and the smooth surface of the older implants did not affect the patterns of migration and wear (Tables 1 and 2).

Discussion

A survival analysis was not within the scope of this paper, but our revision rate [25] might correspond to some other threaded sockets that are no longer recommended for use [6]. The cup

Fig. 3 Example of severe migration of the right hip. On the postoperative radiograph (*left*), there might be a lack of lateral fixation of the cup; the threads seem to have poor contact in the lateral acetabulum. After 10 years (*right*), there was cranio-medial

migration with complete loss of the central bonestock, the lateral threads had gained bone contact, and no obvious wear and osteolysis were found. There was a decrease of inclination from 54 to 37 degrees

Fig. 4 Migration-time diagram for the patient in 3. There was early onset of migration, with significant migration after 1 year (1.9 mm). At 10 years, the cranial migration was 18.1 mm, the medial migration 8.6 mm, and the direction of migration 66 degrees cranio-medially. No change of the migration rate was noted during the follow-up period

we used cannot match the good results of established threaded cups [5] or cups with other modes of fixation [18].

Early migration of an implant means a poor prognosis in the long term [17]. All of the cups we studied were definitely loose at revision. Most of the cups showed significant migration at 2 years, and all cups had migrated at 5 years, which supports the theory of early migration [19]. The change of inclination and anteversion was less sensitive to predicting later revision. There seems to be a lack of initial fixation or an early debonding of most of the cups we studied. In vivo tests in polyurethane bedding showed that the strength of the initial fixation might depend on the quality of the threads, but the results could not be verified in bone [13]. For this implant, no lack of initial fixation during the operation was reported, but some had excessive bone grafting, were malpositioned or malorientated. Furthermore, the threads of this implant were interrupted and relatively narrow, and the spherical shape might contribute to a lower initial stability compared to a conical shape [3]. In contrast to other studies [20], we

found no difference in the patterns of migration between the smooth and the roughened surface, and a poor initial mechanical stability might be of more importance for this cup than the later bone ingrowth.

Some cups seemed to have been well fixed initially and had a late onset loosening. The initial stability might be detected more accurately with the RSA [23]. We could not find reasons for the late onset of loosening. Tallroth et al. [24] examined loose threaded cups for radiographic manifestations of loosening. They found migration in only 9 of 20 cups examined, but most cups had radiolucencies. The lack of detected migration might be explained by a less accurate method of assessment. They took special radiographs to detect eventual osteolysis between the threads. We could not find obvious osteolysis, but minor osteolysis might have been hidden due to oblique projections of the threads.

Most cups had significant wear; the mean wear rate of 0.2 mm/year exceeded the average published wear rates of successful implants [9], and wear rates of more than 0.2 mm/year are seen as increasing the risk for aseptic loosening [4, 12]. Excessive total wear was not found, and there was no evidence that loosening was caused by wear of the polyethylene inlay. There were no obvious signs of osteolysis around the cups or stems, and wear seems not to be a major reason for failure of the implants studied. The cups with a higher wear rate had a higher migration rate. The difference was not significant, but might indicate that debris-induced bone destruction has contributed to the process of migration of the cups [11, 12].

Medial placement of the cup reduced the risk for early migration; the migration rate was lower and the direction of migration was more medial than for laterally placed cups. The laterally placed cups were less stable, and slight medial placement seems favourable as regards loosening. Despite a central bone graft in most of the cases, cups with a central

Table 2 Mean wear, incidence of detectable wear and wear rate for all patients and subgroups of patients

Subgroups	Mean total wear, mm (min-max, SD)	Significant (Mann-W)	Detectable wear (n, %)	Significant (Fisher's)	Mean wear-rate, mm/ year(min-max, SD)	Significant (Mann-W)
All (n=42)	1.0 (0.1–5.4; 0.68)	/	34 (81%)	/	0.20 (0.01–0.99; 0.20)	/
Male (n=22)	1.0 (0.1–5.4; 1.09)	0.38	15 (68%)	0.022	0.20 (0.01–0.99; 0.22)	0.66
>60 years (n=19)	1.1 (0.1–5.4; 1.13)	0.79	15 (78%)	0.82	0.25 (0.01–0.99; 0.27)	0.69
Medially placed (n=8)	0.9 (0.1–1.7; 0.56)	0.86	6 (75%)	0.66	0.15 (0.01–0.32; 0.10)	0.62
Laterally placed (n=14)	0.9 (0.3–1.7; 0.45)	0.96	12 (86%)	0.54	0.21 (0.05–0.99; 0.23)	0.85
Central gap >5 mm (n=24)	0.8 (0.3–1.7; 0.42)	0.89	19 (79%)	0.29	0.21 (0.01–0.99; 0.24)	0.66
Central gap and laterally placed (n=9)	0.8 (0.3–1.7; 0.42)	0.65	7 (78%)	0.82	0.23 (0.05–0.99; 0.28)	0.87
Early migration (n=33)	1.0 (0.1–5.4; 0.94)	0.19	25 (60%)	0.09	0.21 (0.01–0.99; 0.22)	0.79
Smooth surface (n=19)	0.9 (0.1–5.4; 1.18)	0.085	14 (74%)	0.24	0.18 (0.01–1.14; 0.25)	0.12

For the Mann-Whitney U-test and Fisher's test, no significant differences were found between the groups

gap had an accelerated rate of loosening, and the central gap might be a sign of insufficient initial stability. We did not find that malorientation influenced the process of loosening, but an anatomical reconstruction of the centre of rotation and neutral orientation have to be recommended.

Male patients have an increased risk for aseptic loosening [10,18]. We found an increased migration rate for males, but they did not differ in the amount of wear. Micromotion caused by the lack of initial fixation and early migration might do more harm to the bonestock of males due to higher mechanical stress. We have no explanation for a higher incidence of migration for females as described by Bruijn et al. [2] for the threaded Mecring.

The process of early migration for the threaded cup we studied might be caused by excessive peak forces on the bone, leading to stress-induced bone resorption [7, 22, 23] and a lack of central implant-bone contact. The implants started migrating early; the sharpened threads of the loose cups might do further harm to the bonestock in the weight-bearing areas, leading to continuous migration without detectable osteolysis. The process might be accelerated by higher shear forces due to lateral positioning and by wear-induced bone resorption.

Some patients had almost no symptoms and did not come for the recommended follow-up examinations. Thus, severe migration with considerable bone loss had occurred in several cases before aseptic loosening was detected and revision was performed [2]. We recommend regular radiographic follow-up for this type of threaded cup to detect migration at an early stage, avoiding difficult revisions due to severe bone loss. As osteolysis is often absent; the pelvis radiographs have to be examined thoroughly for eventual migration.

Becoming aware of the high number of aseptic loosening, we have discontinued the implantation of this threaded cup [25] and can not recommend further use of this implant.

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