Minimum 10-year Survival of Kerboul Cemented Stems According to Surface Finish

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Abstract The optimal surface finish for a cemented THA stem is still debated. We hypothesized surface finish would influence survival of Kerboul cemented hip arthroplasties and a matte finish would have lower survival. We reviewed survival of 433 total hip arthroplasties in 395 patients: 284 consecutive patients (310 hips) were enrolled in a prospective, randomized study of polished (165 hips) or matte finish stems (145 hips) and compared to a historical series of satin stems (123 hips) in 111 patients. The satin and matte finish implants had similar geometry but the polished was quadrangular rather than oval. Finish roughnesses were: polished (radius, 0.04 μm), satin (radius, 0.9 μm), and matte (radius, 1.7 μm). The mean age of the patients at the time of the index arthroplasty was 63.6 years. The survival rate at 13 years, using radiographic loosening as the end point, was $97.3\% \pm 2.6\%$ for polished stems, $97.1\% \pm 2.1\%$ for satin stems, and $78.9\% \pm 5.8\%$ for matte stems. The data suggest survival of Kerboul stems

was higher with a polished or satin surface finish than with a matte finish.

Level of Evidence: Level II, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

One of the most debated and controversial design factors affecting the survival of cemented femoral components in THA is the surface finish of the implant [11, 20]. The development of stems with increased surface roughness was supported by studies of postmortem specimens and finite element analysis indicating the initiation of cemented femoral component loosening was debonding at the cement-prosthesis interface [5, 14, 15, 21, 22]. Therefore, it was postulated that enhancement of the stem-cement bond through the introduction of rough surfaces (textured, bead-blasted, grit-blasted, and sometimes precoated) would ultimately improve the durability of cemented fixation [4, 33, 34]. Although good results have been reported with a wide range of surface finishes [11, 20, 30], few controlled studies have specifically addressed the effect of surface finish on survival and radiographic loosening rates of cemented stems in the long term [13, 28, 31]. Moreover, the term “rough” as compared with “polished” is not well-defined and has caused some confusion in the literature. The definitions proposed by Garvin and Clark [8] for polished stems (radius of less than 10 μin or 0.25 μm), bead-blasted or satin-finish stems (radius of 20–50 μin or 0.5–1.26 μm), and matte stems (radius of more than 50 μin or 1.26 μm) seem most appropriate.

We introduced a modified polished Charnley stem (Kerboul[®] MKI; Benoist Girard, Stryker Howmedica,

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Herouville Saint-Clair, France) in 1972. The survival rate of this stem was greater than 90% at 20 years using radiographic loosening as the end point [10, 16, 18, 27]. Later, this polished stem became available with a satin and matte surface finish.

Based on the high loosening rates of stems with an unpolished surface finish at short- to midterm followup [1, 2, 7], we hypothesized increased surface roughness would be detrimental to the long-term performance of cemented stems.

Materials and Methods

We enrolled 284 consecutive patients (310 hips) with primary or secondary osteoarthritis of the hip undergoing THA in a prospective, randomized study between January 1988 and December 1989. Patients were randomized to receive either a polished or matte stem of a similar design. There were 175 women and 109 men with a mean age of 64.1 ± 11.5 years (range, 26–91 years), a mean height of 165.7 ± 8.7 cm (range, 145–186 cm), a mean weight of 65.4 ± 11.8 kg (range, 39–105 kg), and a mean body mass index of 23.7 ± 2.9 kg/m² (range, 17.1–34.3 kg/m²) (Table 1). There were 165 hips in the polished stems group and 145 hips in the matte stems group. We obtained a third group of 111 patients with satin-finish stems from an earlier (unpublished) series. The patients in the satin-finish stems (CMK2®; Sanortho, Orthez, France) group underwent surgery between January 1984 and December 1985.

This group included 79 female and 32 male patients (Table 1) with a mean age of 60.5 ± 12.4 years (range, 16–86 years), a mean height of 163.9 ± 8.6 cm (range, 145–182 cm), a mean weight of 63.0 ± 11.5 kg (range, 40–93 kg), and a mean body mass index of 23.4 ± 3.3 kg/m² (range, 13.2–35.3 kg/m²). The satin stems had a surface roughness of $0.9 \mu\text{m}$ (35 μin) and an identical shape to the matte stems with an oval cross-section. Randomization was based upon operating rooms. At a minimum 10-year followup, 246 patients (276 hips) were alive and unrevised, 26 patients (26 hips) had undergone revision, 80 patients (83 hips) died of unrelated causes, and 43 patients (48 hips) were lost to followup (Table 2). The status of 385 of the original 433 hips (89%) was known at the minimum 10-year followup. All patients gave informed consent for treatment and participation in the study.

The Kerboul prostheses combined a 22.2-mm stainless steel femoral head and an all-polyethylene socket. The monoblock femoral stem in each study group (Fig. 1) was derived from the original Kerboul stem (Kerboul® MKI; Benoist-Girard, Stryker-Howmedica). Both stem designs included a stem neck angle of 130°, a 10-mm neck diameter, and a double-taper shape with an angle of 5°. The femoral stem was available in two configurations according to the surface finish. The polished stems had a surface roughness of $0.04 \mu\text{m}$ (1.6 μin) with a quadrangular cross-section (Kerboul® MKIII; Benoist-Girard, Stryker-Howmedica), whereas the matte stems had a surface roughness of $1.7 \mu\text{m}$ (66.9 μin) with an oval cross-section (CMK3®; Vecteur Orthopédic, Marne la Vallée, France).

Table 1. Comparison of demographic data according to surface finish of the stem

Demographic	Polished stems (n = 165)	Satin stems (n = 123)	Matte stems (n = 145)	p Value [†]
Gender ratio (female:male)	0:60	0:71	0:64	0:48
Age (years)*	63.7 ± 11.6 (26.6–91)	60.5 ± 12.4 (16–86)	63.7 ± 11.7 (29.3–87)	0.97
Body mass index (kg/m ²)*	23.6 ± 2.9 (17.1–34.3)	23.4 ± 3.3 (13.2–35.3)	23.7 ± 3.0 (18.4–31.3)	0.87
Underlying disease ratio (primary:secondary osteoarthritis)	0:65	0:61	0:63	0:65
Previous procedure [‡] (osteotomy, shelf, fracture fixation)	22	18	17	0.98
Charnley class [‡]				
A	139	115	124	0.97
B	25	7	20	
C	1	1	1	
Preoperative hip score*				
Pain	3.1 ± 0.9 (1–5)	2.9 ± 0.9 (0–5)	3.0 ± 1.0 (0–5)	0.73
Mobility	4.3 ± 1.5 (0–6)	4.1 ± 1.6 (0–6)	4.5 ± 1.5 (0–6)	0.12
Walking ability	3.7 ± 1.0 (1–6)	3.9 ± 1.0 (0–6)	3.7 ± 1.1 (0–5)	0.94
Global	11.2 ± 2.4 (5–16)	10.8 ± 2.7 (4–15)	11.3 ± 2.7 (4–16)	0.49

* Mean and standard deviation (range); [†]comparisons were performed with Mann-Whitney test except for qualitative variables, which were performed with the chi square test; [‡]hips.

Table 2. Demographic data according to final status of the patient and replacement

Type of Stem	Alive, Unrevised (n = 276)	Dead (n = 83)	Lost to Followup (n = 48)	Revised (n = 26)
Polished stems	109	35	19	2
Satin stems	72	25	14	12
Matte stems	95	23	15	12
Duration of followup* (years)				
Polished stems	11.8 ± 1.3 (10.3–14.2)	6.6 ± 3.6 (0.1–12.3)	5.1 ± 1.9 (2.1–8.3)	11.4 ± 1.6 (10.3–12.6)
Satin stems	14.2 ± 2.3 (10–16)	6.1 ± 4.4 (0.1–13.6)	2.9 ± 2.0 (0.3–7.2)	11.5 ± 3.1 (5–15.9)
Matte stems	11.5 ± 1.3 (10–13.5)	7.4 ± 4.1 (0.1–13.3)	5.4 ± 1.9 (1.2–8.7)	6.9 ± 3.4 (0.9–12.2)
Age at index operation* (years)				
Polished stems	62.4 ± 11.2 (26.6–85)	68.8 ± 10.7 (42.4–87.4)	64.8 ± 12.2 (43.4–91)	42.8 ± 2.3 (41.2–44.4)
Satin stems	58.5 ± 12.4 (16.4–86.4)	67.6 ± 10.1 (50–85.9)	63.0 ± 7.9 (51–78.5)	54.5 ± 14.9 (26.7–76.4)
Matte stems	62.4 ± 10.4 (29.3–87.2)	72.3 ± 11.9 (37.4–85.5)	64.0 ± 14.2 (40.2–82.2)	56.5 ± 11.1 (29.3–68.1)

* Mean and standard deviation (range); n = hips.

The all-polyethylene sockets were sterilized with 3 Mrad of gamma irradiation in air.

All procedures were carried out by two senior surgeons (JPC, MK) through a lateral approach with a trochanteric osteotomy as has been reported previously [17]. Both components were inserted with CMW Type 1 bone cement (DePuy 1, Exeter, Devon, UK). The cement was mixed in air. The cement was hand-packed on the acetabular side. It was packed with a rasp in the femoral canal, which was blocked with a bone plug before cementation. We used no cement gun, pulse lavage, or pressurizer. The femoral component in each study group was cemented according to the French paradox principles [19], including removal of all diaphyseal cancellous bone to obtain a primary stability of the stem before line-to-line cementation.

Postoperatively, patients received anticoagulation therapy, systemic antibiotics, and nonsteroidal antiinflammatory drugs (100 mg ketoprofen per day) to prevent

heterotopic ossification. Passive motion exercises of the involved joint began immediately after the operation with the assistance of a therapist and were continued until active motion of the hip was possible. The patients were free to walk with two supports after 3 days. Full weightbearing was usually allowed after 6 weeks.

All patients were evaluated preoperatively, and most of them had been followed at 6 weeks, 3 months, 6 months, 1 year, and then every 2 years. Attempts were made to interview all 395 patients who had composed the prospective and historic series or to contact their families. The surviving patients were asked to return for clinical and radiographic evaluation. Those who were unable to return were asked to have radiographs made locally and then sent to us for evaluation. Of the 246 patients (276 hips) who were still alive and had not had a revision, 224 (250 hips) were evaluated at a minimum of 10 years clinically and with an anteroposterior radiograph of the pelvis made. The remaining 22 patients (26 hips) were unable to return for a clinical evaluation for reasons not related to the results of the arthroplasty, and they were evaluated by telephone interview by independent observers (FB, NL, MH). Members of the families of the patients who had died were interviewed to determine the function of the hip at the time of death. Hip functional results were rated according to the Merle d'Aubigné grading system [24].

Serial anteroposterior radiographs of the pelvis were analyzed by independent observers (FB, NL, MH, MK). Parameters investigated on the femoral side included progression of radiolucent lines according to the seven zones described by Gruen et al. [9], calcar resorption, and subsidence of the stem. Loosening of the stem was defined according to the criteria of Harris and McGann [12], including stem subsidence equal to or greater than 3 mm, cement mantle fracture, complete radiolucent line equal to or greater than 2 mm, or radiolucent line in Zone I equal to

Fig. 1 The Kerboul polished (left), satin (middle), and matte (right) stems used in this study are shown.

or greater than 2 mm. Periprosthetic cystic or scalloped lesions exceeding 2 mm in diameter that had not been noted on the immediate postoperative radiograph were defined as osteolysis.

We performed a survivorship analysis according to the actuarial method using revision for any reason, revision for aseptic loosening, and radiographic loosening of either component at the time of followup as the end points. The survival curve was derived from the cumulative survival rate over time as calculated from the actuarial life table [23]. The standard error, given as a percentage, and the 95% confidence intervals were calculated from the data in the life table. The log-rank test was used for the statistical comparison of the survivorship analysis group [26]. The influence of stem surface loosening rates was analyzed with the chi square test or Fisher's exact probability. Comparison of preoperative and last followup clinical parameters was performed using the Wilcoxon rank test. Clinical outcome according to the stem surface was analyzed using the Kruskal-Wallis test. Significance was determined with StatView statistical software (version 5.0; SAS Institute, Cary, NC) and was defined as $p < 0.05$.

Results

Two hundred forty-six patients (276 hips) had their original implants in place (Table 2). Twenty-six patients (26 hips) had revision of one or both components (Table 2). The mean duration (and standard deviation) until revision was 9.5 ± 3.9 years (range, 0.8–16 years).

Twenty stems were radiographically loose after a minimum 10-year followup. The total rate of femoral loosening, including revision after a minimum 10-year followup, was 0.6% (one of 165), 3.3% (four of 123), and 10.3% (15 of 145) for the polished, satin, and matte stem groups, respectively (Fig. 2). The rates differed ($p < 0.0001$) for the polished versus the matte stems and the satin versus the matte stems ($p = 0.03$), but not for the polished versus the satin stems ($p = 0.17$). Except for one isolated femoral satin stem loosening, the loosened stems in the satin and polished groups of patients were associated with high polyethylene wear and periacetabular osteolysis with limited femoral osteolysis (Fig. 3). On the contrary, among the 15 loosened matte stems, high polyethylene wear was observed only in three hips. All hips with matte stem loosening were associated with extensive femoral osteolysis. Moreover, loosening of matte stems occurred at the bone-cement interface as indicated by clearly delineated radiolucent lines at the bone-cement interface (Fig. 4).

With revision of the femoral component for any reason as the end point, the survival rate was greater ($p = 0.003$) for the polished versus the matte stems, but not greater for

Fig. 2A–B (A) This postoperative radiograph of a Kerboul THA shows a polished stem in a 60-year-old woman with primary osteoarthritis of the hip. (B) At the 14-year followup, there was no measurable wear of the socket and no sign of loosening on the femoral side.

Fig. 3A–B (A) This postoperative radiograph of a Kerboul THA shows a polished stem in a 45-year-old woman with hip dysplasia. (B) At the 12.6-year followup, there was major polyethylene wear responsible for socket loosening and periacetabular osteolysis. The femoral component has subsided and tilted in a varus position. Osteolysis on the femoral side is limited to the proximal femur around the calcar.

the polished versus the satin stems and for the satin versus the matte stems (Table 3). With radiographic femoral loosening including loosened revised stems as the end point, polished stems had greater ($p < 0.0001$) survival than the matte stems and the satin greater ($p = 0.0004$) than the matte stems, but the polished and satin stems had similar survival (Table 3). The apparent mechanisms of loosening differed. The intraoperative findings at revision were different among the stem surface groups. In the hips

Fig. 4A–B (A) A postoperative radiograph of a Kerboul THA shows a matte stem in a 45-year-old woman with hip dysplasia. (B) At 5.6-year followup, the femoral implant had subsided and tilted in a varus position. There was no measurable wear of the socket. Failure occurred at the bone-cement interface with clear radiolucency at that interface associated with extensive femoral osteolysis.

with a polished or satin surface, the cement mantle was continuous, and during removal, the stem was easily separated from the intact cement. In contrast, in the hips with a matte surface, the failure occurred at the bone-cement interface. The cement remained firmly attached to the stem, and the cement-stem composite was usually removed in one piece (Fig. 5).

The stem surface did not influence either the global hip score or any of the three parameters of the Merle d'Aubigné scale (Fig. 6) for the 246 patients (276 hips) who were alive and had no revision at the time of the minimum 10-year evaluation. There were 165 female and 81 male patients. The mean Merle d'Aubigné functional hip score increased ($p < 0.001$) from 11.2 ± 2.6 points preoperatively to 17.4 ± 0.6 points at the time of the last followup.

Fig. 5 A revised matte stem shows the cement remained firmly attached to the stem at removal.

Postoperative complications occurred in 20 of the 395 patients (5%) and were evenly distributed in the three groups. Postoperative dislocation of the hip occurred in eight patients, and three of them underwent revision of both components. Five nonunions of the greater trochanter were observed. Two patients had deep vein thromboses without pulmonary embolism. Three patients had deep infection and were treated successfully by one-stage revision.

Discussion

The clinical use of unpolished stems for cemented fixation was supported by in vitro studies and analysis of post-mortem specimens after up to 17 years in vivo; it was concluded the weak link in the long-term performance of

Table 3. Survival of the stem according to the surface finish

Type of stem	Number of failures	Cumulative survival (%)	Standard error (%)	95% Confidence interval
<i>Revision for any reason as the end point</i>				
Polished stems (n = 165)	2	96.3	2.8	90.8–100
Satin stems (n = 123)	12	91.4	3.2	85.2–95.4
Matte stems (n = 145)	12	87.2	4.2	78.9–95.4
<i>Radiographic loosening as the end point</i>				
Polished stems (n = 165)	1	97.3	2.6	92.2–100
Satin stems (n = 123)	4	97.1	2.1	93–100
Matte stems (n = 145)	15	78.9	5.8	67.6–90.3

n = hips.

Fig. 6 Preoperative and last followup of the Merle d'Aubigné hip score parameters. The values are given as mean and standard deviation. There was no difference among the three groups (Kruskal-Wallis test, $p = 0.77$).

cemented femoral components was the metal-cement interface [14, 15, 21, 22]. Indeed, it was postulated from these studies that loosening and subsequent femoral osteolysis were initiated by proximal and distal debonding at the metal-cement interface. Our aim was to evaluate the effect of stem surface finish on the clinical and radiographic performance and to determine the optimal surface finish for a cemented stem.

A limitation of this study was the design of the polished stems was not identical; their cross-section was quadrangular as opposed to the oval of the satin and matte stems. However, the coronal and sagittal shapes of the three stems were similar with a regularly decreasing cross-section area according to an angle of 5° . Moreover, none of the stems used in this study had a cylindrical shape, which has been demonstrated to increase loosening as a result of rotational instability [25]. The satin stem series was historic rather than concurrent, and certain aspects of the surgery or postoperative care may have differed. At the time the randomized study (satin versus matte finishes) was conducted, there were no previous data in the literature and we did not perform a sample size power analysis: the numbers of patients were chosen arbitrarily. Moreover, the randomization process was not sophisticated and only based on operating rooms. No statistician participated at that time. Although we did not stratify by diagnosis, comorbidities, or other potentially confounding variables, the three groups of patients were comparable in terms of demographics, preoperative functional status, surgical technique including operating surgeons and mode of cementation, and postoperative regimen. All patients were evaluated clinically and radiographically after a minimum 10-year followup with less than 10% of patients lost to followup.

The data suggest the matte stems had a lower survival rate with radiographic loosening as the end point when

compared with polished and satin stems. Similar results have been reported with other stem designs cemented according to modern cementing techniques. Howie et al. [13] compared 20 polished (radius, $0.01\text{--}0.03\text{ }\mu\text{m}$) with 20 matte (radius, $0.7\text{--}1.3\text{ }\mu\text{m}$) Exeter stems (Stryker, Howmedica, Rutherford, NJ) after a minimum 9-year followup. In the matte stems group, revision for femoral aseptic loosening was performed in four hips, whereas no polished stem was revised for loosening. Ong et al. [28] reported on 254 uncoated satin finish Harris Design-2 stems (radius, $0.75\text{ }\mu\text{m}$) (Howmedica) with a mean followup of 13.5 years versus 514 methylmethacrylate precoated stems (Zimmer, Warsaw, IN) of similar geometry with a mean followup of 8.4 years. Two precoated stems were used, including the Harris Precoat stem (not textured; radius, $0.8\text{ }\mu\text{m}$) and the Harris Precoat-Plus stem (proximally textured; radius, $2.2\text{ }\mu\text{m}$). Failure was defined as revision or pending revision, progressive complete radiolucent line greater than 2 mm, stem migration, or stem fracture. The coated stems failed at a higher rate; at least 10 (eight revised, two radiographically loose) of the 254 uncoated stems (3.9%) and at least 49 (43 revised, six radiographically loose) of the 514 precoated stems (9.5%) had failed at a mean followup of 9.9 and 5.7 years, respectively. The most extensive literature that has been published concerning the effect of surface finish has been reported with the Iowa stem (Zimmer) [1–3, 25, 28, 31]. Indeed, this cobra-shaped femoral component has been developed with a polished (radius, $0.1\text{ }\mu\text{m}$), satin (radius, $0.8\text{ }\mu\text{m}$), and grit-blasted methylmethacrylate proximally precoated (radius, $2.1\text{ }\mu\text{m}$) surface finish. Sporer et al. [31] compared 36 satin stems with 45 grit-blasted stems in patients younger than 50 years old after a mean followup of 11.3 and 8.2 years, respectively. Using revision of the femoral component resulting from aseptic loosening as the end point, the survival rate of 93% at 10 years was greater for the satin stems compared with 86% at 7 years for the grit-blasted stems. The survival rate using loosening of the femoral component (with or without revision) as the end point was 91% at 10 years for the satin stems versus 84% at 7 years for the grit-blasted stems. Collis and Mohler [3] reported on 122 polished and 122 grit-blasted Iowa stems after a mean followup of 5.8 years. Six hips in the grit-blasted stem group had femoral aseptic loosening, including four revised stems, whereas none of the polished stems were loosened. Recently, Della Valle et al. [6] compared 64 textured (radius, $1.75\text{--}2.5\text{ }\mu\text{m}$) with 138 satin-finish ($0.5\text{ }\mu\text{m}$) Versys stems (Zimmer) after a followup of 4 to 8 years. They reported more stems (seven hips) in the textured group failed than in the satin surface group (no failed hips). Two prospective, randomized studies compared similar stems differing only by the surface finish [29, 32]. Neither showed differences in femoral loosening and revision rates.

However, in both of these studies, the so-called rough stems had a matte finish only on the proximal third of the implant (radius, 4.25 μm and 2.75 μm , respectively), whereas the distal portion of the stem was either highly polished (radius, 0.1 μm) or had a satin surface finish (radius, 0.75 μm). Moreover, the mean followup was 4.8 and 6.5 years, respectively.

Based on our study and the review of the literature, it appears femoral cemented fixation is more reliable in the mid- to long-term with either a polished (radius, less than 0.25 μm) or satin (radius, 0.5–1.26 μm) surface finish irrespective of the stem design and the cementing technique. There remains, however, some controversy over the mode of loosening of matte stems. Some authors [2, 3, 6, 25] describe the initial event as the debonding of the proximal stem from the cement in Zone I of Gruen et al. [9]. The rough stem would then produce cement abrasion, leading to particle production, osteolysis, and subsequent stem loosening. Others consider the primary event is failure at the bone-cement interface leading to loosening of the cement-stem composite and subsequent femoral osteolysis [7, 28]. This second hypothesis appears more consistent with our data. Based on our experience with different surface finishes, we have completely abandoned the use of femoral components with rough surfaces and currently use highly polished stems exclusively.

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