Hip revisions with impacted morselized allograft bone and cement

Patient outcome, prosthetic fixation and risks

Ewald Ornstein

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From the Departments of Orthopedics,
County Hospital Hässleholm–Kristianstad, Hässleholm
and Lund University Hospital, Lund, Sweden

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Front-page illustrates a map of Scania (southern part of Sweden)
showing the localizations of the main participating Departments.

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II. Radiostereometric analysis in hip revision surgery – optimal time for index examination. Ornstein E, Franzén H, Johnsson R, Sundberg M. Acta Orthop Scand 2000; 71 (4): 360-364.

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IX. Early complications after one hundred and forty-four consecutive hip revisions with impacted morselized allograft bone and cement. Ornstein E, Atroshi I, Franzén H, Johnsson R, Sandquist P, Sundberg M. J Bone Joint Surg Am 2002; 84 (8): 1323-1328.

Background

Total hip replacement in general

Sir John Charnley, the inventor of the modern total hip replacement, started the most successful era in modern orthopaedic history (Figure 1). Few medical interventions have had similar impact on pain and patient autonomy. Total hip replacement is also one of the most cost-effective surgical procedures in medicine (Berry et al. 2002). For many years the dominant hip replacement all over the world was bearing John Charnley's name (Waugh 1990).

When a problem is solved there are always pros and cons. In the case of the low-friction hip replacement the pros with long-lasting pain reduction and patient autonomy widely dominate over the cons. This has to be kept in mind when discussing problems or drawbacks with surgery dealing with hip replacement.

The first cons faced were the problems of infection and the insufficiency of the prosthetic material. In the early years of total hip replacement Charnley and Eftekar (1969) reported a deep infection rate of 9% and Wilson and co-workers (1972) reported a deep infection rate of 13%. Refinements of surgical technique, ultra clean operating theaters, body-exhaust systems, antibiotics administered intravenously and in cement led to infection rates below 1% (Herberts et al. 1995). Currently the infection rate in Sweden is as low as 0.2% (Herberts and Malchau 2000, Lidgren 2001). New designs of and new materials in femoral stems made stem-breakage become a rarity (Charnley 1975).

In the early part of the hip replacement era there was great concern about systemic complications such as deep venous thrombosis and pulmonary embolism. Modern treatment has diminished these serious complications; symptomatic pulmonary embolism occurs in less than 0.5% of the patients and fatal pulmonary embolism in less than 0.2% (Freedman et al. 2000). Advances within anesthesiology and internal medicine have improved the ability to perform surgery on very old patients. Sudden death during hip replacement surgery has declined from 0.09% to below 0.025% (Parvizi et al. 1999).

Figure 1. An original cemented Charnley prothesis with a flat-backed stem 28 years after primary hip replacement that was performed in a 47-year-old woman.

In the 1960s, patients undergoing hip replacement at Wrightington hospital in England, where John Charnley worked, were informed that "Once the operation is completed there is nowadays almost nothing that can go mechanically wrong!" (Waugh 1990). However, Charnley in his book *Low friction arthroplasty* in 1979, stated that "The challenge comes when patients between 45 and 50 years of age are considered for the operation". This means that after a total hip replacement, the longer the patient lives and is active physically the greater is the risk for aseptic loosening of the prosthesis necessitating surgical revision. This is now the major con of total hip replacement.

A long-term follow-up of Charnley's low-friction replacements performed 1962 to 1990 at

Wrightington Hospital was recently published with revision for any indication as the end-point (Wroblewski et al. 2002). The 1092 patients (1434 hips) were all below 50 years of age (mean 41 years) at the time of surgery. The prosthetic survival rate was 94% at 10 years, 85% at 15 years, 74% at 20 years and 55% at 27 years. The overall revision rate for aseptic loosening was more than twice as high for sockets (12%) as for stems (5%).

Kavanagh and co-workers from the Mayo Clinic in Rochester, USA, reported a 20-year follow-up of the first 333 Charnley hip replacements performed on patients with a mean age of 65 years using the 1st generation cementing technique (Kavanagh et al. 1994). The results revealed that 16% had been revised and in another 17% probable loose sockets and in 36% probable loose stems were found. At the same Department, Berry and co-workers performed a 25-year follow-up of 2000 Charnley prostheses showing that in 90% of the stems and sockets no revision because of aseptic loosening had been performed (Berry et al. 2002).

The Charnley prosthesis was also the first total hip replacement used at the Department of Orthopaedics at the University Hospital in Lund and at the University Hospital MAS in Malmö, Sweden. The 20-year follow-up of the 377 hips from Lund operated on with the 1st generation cementing technique because of osteoarthrosis revealed a prosthetic survival rate exceeding 85% (Johnsson et al. 1994). The 10-year follow-up of 402 hips from Malmö revealed a prosthetic survival rate of 95% in a group of patients with rheumatoid arthritis and of 89% in a group of patients with osteoarthrosis (Önsten et al. 1994).

Since the era of the original Charnley prosthesis both the surgical technique and prosthetic design have developed and diversified, as shown by improved cementing technique (Fowler et al. 1988, Schulte et al. 1993, Estok and Harris 1994, Mulroy and Harris 1996, Sochart and Porter 1997, Madey et al. 1997, Sochart and Porter 1998, Smith et al. 2000, Williams et al. 2002) and the use of uncemented prostheses (Heekin et al. 1993, Xenos et al. 1995, Berry et al. 1995, Capello et al. 1997, Hellman et al. 1999, McLaughlin and Lee 2000, D'Antonio et al. 2001) and hybrid prostheses (1 prosthetic component cemented and the other uncemented) (Harris and Maloney 1989, Schmalzried and Harris 1993, Smith and Harris 1997). Many of the new prosthetic designs have yielded promising mid-term to long-term prosthetic survival rates but no innovation has reported long-term follow-up matching that of the Charnley prosthesis.

Each year more than one million hip replacements are performed worldwide (Garellick et al. 1999). In the USA more than 200 000 hip replacements are performed annually and the number is increasing (Hou and Cook 2001). In Sweden, 12 256 primary hip replacements and 1398 revisions were performed during 2001, corresponding to 138 and 16 per 100 000 inhabitants, respectively (*www.jru.orthop.gu.se*). Approximately 75% of the revisions were performed because of aseptic loosening. The cumulative revision rate for aseptic loosening at 10 years after total hip replacement has declined three-fold in Sweden from 9% among patients operated on during 1979 to 3% among patients operated on during 1987 (Herberts and Malchau 2000). However, the revision burden (i.e. the fraction of revisions of all total hip replacements) has been relatively constant at approximately 8% during the last decade in Sweden (*www.jru.orthop.gu.se*).

Aseptic loosening and revision of total hip replacement

The pathological basis for aseptic loosening, which is the major reason for revision of total hip replacement, is still debated. Several etiologies for impaired prosthetic fixation and periprosthetic osteolysis have been proposed. Evidence has been presented for the following possible etiologies: (1) heat produced during cementing (Willert et al. 1974, Mjöberg et al. 1984, Mjöberg et al. 1986, Mjöberg 1991), (2) debonding of the stem from the cement (Maloney et al. 1989, Jasty et al. 1990, Jasty et al. 1991, Harris 1992, Harris 1994, Verdonschot and Huiskes 1997, Berry et al. 1998), (3) foreign body reaction to wear particles from metal, cement and/or polyethylene (Harris et al. 1976, Jasty et al. 1986, Maloney et al. 1990, Jiranek et al. 1993, Maloney and Smith 1995, Walker 2000), (4) prosthetic micromovements raising high pressure waves between cement and bone or pumping joint fluid through cement defects yielding high

Figure 2. Severe osteolysis in the proximal femur 14 years after primary hip replacement with a Spectron prosthesis.

Figure 3. Femoral fracture 16 years after a primary hip replacement with a Charnley prosthesis.

pressure obstruction of the vascularized bone adjacent to the cement (Radin et al. 1982, Maloney et al. 1989, Burke et al. 1991, Engh et al. 1992, Mjöberg 1997, Aspenberg and Van der Vis 1998, Van der Vis et al. 1998, Nivbrant 1999), and (5) stress shielding (Huiskes et al. 1992). Although the arguments for each etiology have been more or less convincing, the final explanation for aseptic loosening might be sought in a combination of multiple etiologic factors.

A serious consequence of the process of aseptic loosening with osteolysis is the development of bone stock deficiency (Figure 2). This can lead to fractures as well as to impaired conditions for anchorage of the prosthetic components in future revision surgery (Figure 3).

As in primary hip replacement, the revision problem might be managed with conventional cementing techniques (Amstutz et al. 1982, Callaghan et al. 1985, Kavanagh et al. 1985, Marti et al. 1990, Kershaw et al. 1991, Estok and Harris 1994, Raut et al. 1995a, Raut et al. 1995b, Raut et al. 1996, Hultmark et al. 2000, Eisler et al. 2000), uncemented techniques (Pak et al. 1993, Malkani et al. 1995, Peters et al. 1995, Berry et al. 1995, Mulliken et al. 1996a, Mulliken et al. 1996b, Krishnamurthy et al. 1997, Engh et al. 1998, Paprosky 1998) or hybrid techniques. But these techniques do not specifically address the problem with bone stock deficiency (Leopold et al. 2000, Goldberg 2000).

In elderly patients with minor bone stock deficiency, conventional cementing technique might be sufficient but no bone stock restitution can be expected (Hultmark et al. 2000, Eisler et al. 2000). Some stem designs might facilitate bone stock restitution (Wagner 1987, Kolstad 1994, Isacson et al. 2000). However, the most common solution used for bone stock deficiency in both femoral and acetabular revision is bone grafting (Goldberg 2000). Autograft bone is the obvious primary choice (Huo et al. 1992, Garbuz et al. 1998, Bauer and Muschler 2000). The results of using structural autografts in the reconstruction of the acetabulum in primary hip replacement (Harris et al. 1977, McGann et al. 1986, Gerber and Harris 1986, Mulroy, Jr. and Harris 1990, Head et al. 1995, Shinar and Harris 1997) have been disappointing but cancellous autografts have performed well in cases of protrusion of the acetabulum (Hastings and Parker 1975, McCollum et al. 1980, Johnsson et al. 1984, Slooff et al. 1984, Johnsson et al. 1986, Gates et al. 1990). The femoral head, which is one of the main sources of autograft, is not available in hip revision. Also, because in hip revision a large amount of bone graft is often needed, autograft is usually insufficient (Boyce et al. 1999). To solve this problem the use of allograft bone for reconstruction of large bone stock deficiencies began in the late 1980s (Gross et al. 1987, Paprosky et al. 1994a, Paprosky and Magnus 1994b, Mulliken et al. 1996c, Gross et al. 1999, Haddad et al. 2002). Allograft bone was used not only for contained (cavitary) but also for uncontained (segmental) bone stock deficiencies in both stem and socket revisions.

In Exeter, England, the orthopaedic surgeons started in a broader manner to impact morselized allograft bone, obtained from fresh-frozen femoral heads, into the femoral canal. In Nijmegen, the Netherlands, the same method was used in the acetabulum. The purpose was to get a stable reconstruction and biological bone stock restitution.

History of impacted morselized allograft bone and cement in hip revision

Reports on hip revision with impacted morselized allograft bone and cement

Authors	Year	Stems	Sockets	FU years	Revised	Prosthesis	Focus
Simon et al.	1991	38	0	1	1	Exeter	Clinical, radiographic
Gie et al.	1993a	56	0	1.5–4	1	Exeter	Clinical, radiographic
Ling et al.	1993	1	0	2-11	-	Exeter	Histology
Slooff et al.	1993	0	88	?	4	?	Surgical technique
Gie et al.	1993b	-	-	-	-	Exeter	Surgical technique
Schreurs et al.	1994	-	-	-	-	Femoral	Experimental in goats
Capello	1994	17	0	?	0	?	Surgical technique
Azuma et al.	1994	0	24	6	0	Physio-hip	Clinical, radiographic
Elting et al.	1995	35	0	2–5	2	?	Surgical technique
Nelissen et al.	1995	4	0	1–2.25	0	CPT	Histology
Franzén et al.	1995	5	0	1	0	Collared stems	Clinical, RSA
Elting et al.	1995	56	0	2.5	2	CPT	Clinical, radiographic
Weidenhielm et al.	1995	89	0	0–3.5	0	CPT	Surgical technique
Slooff et al.	1996	10	88	2–11	4	Exeter stem	Clinical, radiographic
Buma et al.	1996	0	8	0.1–6	-	Different	Histology
Berzin et al.	1996	7	0	-	-	Precoat	Stability, cadaver
Gie et al.	1996	68	0	5–8	1	Exeter	Clinical, radiographic
Smith et al.	1996	8	0	-	-	Exeter	Stability, experimental
Ling	1996	41	0	4.5–7	1	Exeter	Clinical
Malkani et al.	1996	5	0	-	-	CPT	Subsidence, cadaver
Meding et al.	1997	34	0	2.5	2	CPT	Complications
Hydahl et al.	1997	50	0	0.5–2	?	CPT	Fractures
Eldridge et al.	1997a	79	0	1	8	Exeter and CPT	Massive subsidence
Eldridge et al.	1997b	18	0	-	-	Exeter	Graft size, experimental
Masterson et al.	1997b	187	0	0.25	?	Exeter, CPT, Precoat	Cement mantle
Masterson et al.	1997a	35	0	0.5	0	Exeter	Cement mantle
Masterson & Duncan	1997	-	-	-	-	-	Review article
Ling	1997	-	-	-	-	Comment	Malkani et al. 1996
Williams & Maheson	1997	75	0	2	?	CPT	Surgical technique
Chassin et al.	1997	4	-	-	-	Precoat	Extended osteotomy
Elting et al.	1998	147	0	2–8	2	?	Clinical
Duncan et al.	1998	-	-	-	-	-	Review article
Tägil & Aspenberg	1998	-	-	-	-	-	Experimental in rats
Schreurs et al.	1998	0	48	10–15	5	Müller, Allopro	Clinical, radiographic
Schimmel et al.	1998	-	-	-	-	Acetabular	Experimental in goats
Ullmark & Linder	1998	1	0	0.5	1	Charnley	Histology
Ornstein et al.	1999	2	0	2	0	Exeter	RSA, interfaces

Reports on hip revision with impacted morselized allograft bone and cement continued

Authors	Year	Stems	Sockets	FU years	Revised	Prosthesis	Focus
Haddad & Duncan	1999	-	-	-	-	-	Review article
Masterson et al.	1999	50	0	0	0	Charnley elite	Cement mantle
Michail et al.	1999	43	0	6	1	CPT	Clinical, radiographic
Ornstein et al.	1999	19	21	2	0	Exeter	RSA migration
Jazrawi et al.	1999	2	-	-	2	CPT	Stem fracture
Kärrholm et al.	1999	24	0	2.5	0	Spectron EF	RSA, DEXA, radiographic
Ullmark & Nilsson	1999	-	-	-	-	-	Graft strength and recoil
Leopold et al.	1999	25	0	5	2	Precoat	Complications
Ornstein et al.	2000	6	5	2	0	Exeter	Early RSA migration
Tägil	2000	-	-	-	-	-	Experimental in rats, rabbits
Leopold et al.	2000	-	-	-	-	-	Review article
Wang et al.	2000	-	-	-	-	-	Experimental in rats, rabbits
Van Biezen et al.	2000	21	0	5	0	Exeter	Complications, subsidence
Pekkarinen et al.	2000	36	0	3	2	Exeter	Complications
Knight & Helming	2000	30	0	3	1	CPT	Complications
Ullmark	2000	-	-	-	-	-	Graft stability
Linder	2000	14	0	0.5–8	-	Exeter, CPT, Charnley	Histological, radiographic
Flugsrud et al.	2000	10	0	4	0	CPT, Exeter	Clinical., radiographic
Ornstein et al.	2001	18	17	2	0	Exeter	RSA migration
Tägil & Aspenberg	2001	-	-	-	-	-	Experimental in rats
Schreurs et al.	2001	0	18	10-18	2	Müller, Allopro	Clinical, radiographic
Thien et al.	2001	0	7	5–9	1	Charnley-Muller	Radiological, freeze dried
De Roeck & Drabu	2001	32	32	4	3	Charnley	Clinical, freeze dried
Bavadekar et al.	2001	-	-	-	-	-	Stiffness of graft
Boldt et al.	2001	79	173	4	4–5	Charnley	Complications, clinical
Fetzer et al.	2001	26	?	4–8	0	Collored stem	Complications, clinical
Van Doorn et al.	2002	1	0	3.4	-	Exeter	Stem fracture
Lind et al.	2002	86	0	3.6	3	Exeter	Survival, complications
Ullmark et al.	2002	57	0	6.5	8	Charnley, Lubinus SPII	Clinical, radiographic
Ullmark & Obrant	2002	18	0	0.1–4	-	Charnley, Lubinus SPII	Histology
Piccaluga et al.	2002	54	0	2–12	2	Charnley	Clinical, complications
Van Donk et al.	2002	-	21	0.3–15	-	-	Histology
Stulberg	2002	-	-	-	-	-	Surgical technique
Gore	2002	26	0	2–4	?	CPT	Complications
English et al.	2002	44	?	2–10	1	Exeter	Deep infection
Kligman et al.	2002	50	0	3–7	3	MS 30	Allograft source
Ornstein et al.	2002	108	130	1	3	Exeter	Complications

History of the Exeter hip prosthesis and the X-change revision instruments system

John Charnley demanded lateral approach with osteotomy of the greater trochanter to insert the low-friction hip prosthesis. The orthopaedic surgeon Professor Robin S. M. Ling (Princess Elizabeth Orthopaedic Hospital, Exeter) and the engineer Dr. Clive Lee (School of Engineering, University of Exeter) had the ambition to perform a low-friction hip replacement with a prosthesis specifically intended for insertion through a posterior approach.

The straight configuration of the stem should provide a more controlled insertion compared to earlier types of designs (Figure 4). This configuration, in combination with the double tapered shape, was assumed to be the most appropriate geometry for extrusion of the cement dough into the endosteal trabecular bone of the femoral canal during insertion of the stem. Because femoral heads with a large diameter have relatively larger frictional torque and because small femoral heads had been a problem in sockets of Teflon (Charnley 1963), the inventors decided to design a socket with a bearing diameter of 30 mm and a femoral head of 29.75 mm. The reason why the stem had a polished surface was that it was "the fashion" at the time.

After initial problems with fatigue fracture of the stem and a period with matte surface of the stem and metal backed socket, the Exeter prosthesis has maintained the same composition and design since 1988. A hollow centralizer of polymethylmethacrylate has been introduced to guarantee that the stem will not be end-bearing but will allow few

Figure 4. Prosthetic components: stem, socket and centralizer of an Exeter Universal hip.

Figure 5. Primary hip replacement with a cemented Exeter Universal hip.

Figure 6A. The X-change revision instruments system for stem revision developed by the Exeter group (Gie et al. 1993b).

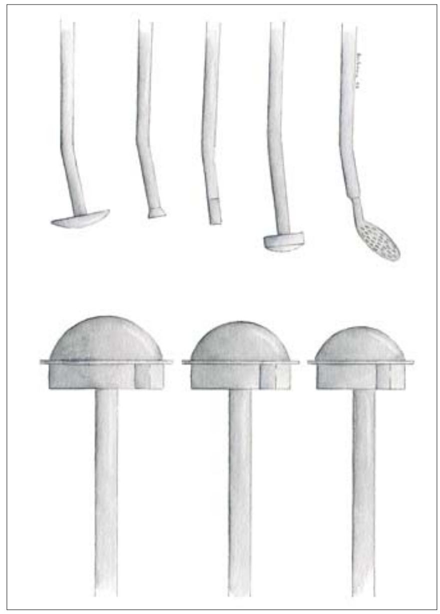


Figure 6B. The X-change revision instruments system for socket revision developed by the Nijmegen group (Slooff et al. 1993).

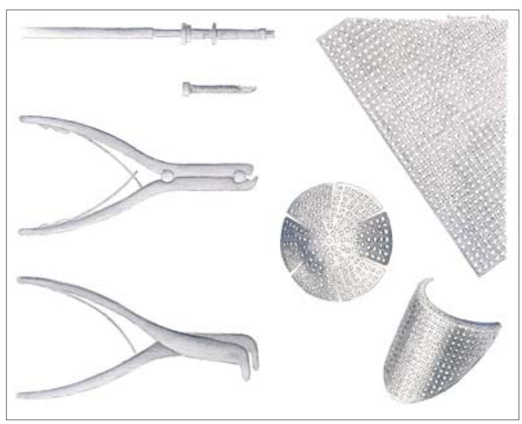


Figure 6C. The X-change revision mesh instruments system for the femur and the pelvis.

millimeters of stem subsidence within the cement mantle (Figure 4 and 5). Using this concept (commercialized as Exeter Universal) and the 3rd generation or contemporary cementing technique (Ling 1997a) in 325 primary hip replacements, no stem and only 4 sockets were revised for aseptic loosening and an additional 3 sockets were considered to be loose at follow-up 8 to 12 years after surgery (Williams et al. 2002).

In 1985 a patient with large bone stock deficiency in the proximal femur because of aseptic loosening of a hip prosthesis was operated on with impaction of morselized allograft bone and insertion of an Exeter stem without cement (Ling 1997b). The patient had pain relief and radiographic follow-up suggested some bone stock restitution. This experience together with the findings by Slooff and co-workers (1984) using morselized allograft bone and cement in the acetabulum led the Exeter group to adapt the technique to femoral hip revision (Simon et al. 1991, Gie et al. 1993a, 1993b).

At the beginning of the femoral allograft impaction era ordinary stems or trial prostheses were used for impaction of the allograft bone. After impaction a stem of a smaller size than that used for impaction was cemented into the neo-medulary canal in the same manner as in primary hip replacement. A special instrumentation setup was successively created and was eventually commercially available (X-change Revision Instruments System) in 1992 (Figure 6A and 6B). In addition, a number of special flexible stainless steel meshes have been manufactured for achieving containment in both femur and acetabulum in cases with skeletal defects (Figure 6C). To facilitate bypassing bone loss or cortical defects longer femoral stems (up to 260 mm) are now available.

Local history of hip revision with impacted morselized allograft bone and cement at the Department of Orthopaedics Hässleholm-Kristianstad

After having the opportunity to participate in a hip revision with impacted morselized allograft bone and cement performed by Dr. Graham Gie on the 11th of December 1991 in Ängelholm, Sweden, we at the Department of Orthopaedics in Hässleholm County Hospital, Sweden, became interested in that surgical procedure. The procedure was at that time an experimental technique for solving the problem of bone stock deficiency in hip revision surgery. Shortly after their pioneering publication in the British Journal of Bone and Joint Surgery at the beginning of 1993, Gie and co-workers gave an instructional course in Helsingör, Denmark, which we attended. Because the method provided promising results we decided to "import" this hip revision technique to our department. We decided that the introduction of the technique would follow a rational plan strictly defining inclusion criteria, logistics and follow-up content in a scientific manner.

Figure 8. Archive with patient files, follow-up protocols, radiographs and RSA-examinations.

Figure 7. Hip revision with impacted morselized allograft bone and cemented Exeter prosthesis.

Prior to the first hip revision in January 1994 one of our surgeons visited Princess Elizabeth's Orthopaedic Hospital, Exeter, England, for six weeks to become familiar with the revision technique developed at that hospital. The surgeon who had received prior training performed the first 29 hip revisions with this technique at our department while two other surgeons assisted and became familiar with the revision technique (Figure 7).

The surgical intention was to perform all hip revisions, except those excluded by defined criteria, with impacted morselized allograft bone and cement as described by the inventors of the technique in Exeter and Nijmegen. The scientific intention was to prospectively follow all patients submitted to this new and technically demanding revision procedure and to monitor the patient outcome with a validated outcome instrument, the prosthetic fixation with radiostereometric analysis (RSA), and the surgical risks with a detailed standardized protocol (Figure 8).

Aims of this thesis

The general aim of this thesis was to study patient outcome, prosthetic fixation and surgical risks in hip revision with impacted morselized allograft bone and cement as described by the inventors of this revision technique in Exeter and Nijmegen.

The specific aims were:

- To assess quality-of-life outcomes in revision compared to those in primary replacement using a validated outcome instrument.
- To investigate with weekly RSA the initial prosthetic migration pattern from the 1st day after revision and before mobilization to 6 weeks after surgery.
- To assess with RSA whether the collarless, double tapered and polished Exeter stem subsided within the cement mantle and/or the stem-cement beam subsided relative to the femur.
- To investigate with RSA the migration pattern of the stem up to 5 years after revision and to estimate whether early stem migration predicted future migration.
- To assess possible correlations between stem migration measured with RSA and conventional radiographic findings regarding bone stock deficiency, quality of bone packing, cement mantle, stem positioning, radiolucent lines and allograft bone appearance.
- To investigate with RSA the migration and rotation patterns of the socket up to 5 years after revision and to estimate whether early socket movements predicted future migration and rotation.
- To assess possible correlations between socket migration and rotation measured with RSA and conventional radiographic findings regarding bone stock deficiency, radiolucent lines and allograft bone appearance.
- To assess with RSA whether free weight bearing initiated immediately after revision was detrimental for prosthetic fixation.
- To prospectively register and analyze all complications and technical incidents that occurred during revision and within the 1st year after surgery.

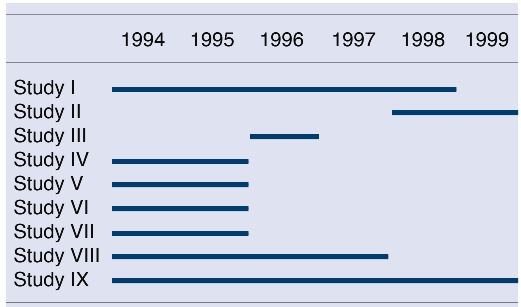
Patients

The catchment area for the Department of Orthopaedics Hässleholm-Kristianstad, the northeast part of Scania, has a population of 170,000, whose demographics are similar to those of the Swedish general population (Statistics Sweden. Official statistics of Sweden: population statistics 1997. Available from: http://www.scb.se/scbwse/borhtm/folk97al.htm). In 2001, 240 primary hip replacements and 24 hip revisions were performed on patients from northeast Scania, corresponding to 142 and 14 per 100,000 inhabitants, respectively (Statistics Region of Scania and Malchau H, Swedish National Hip Arthroplasty Register, personal communication 2002). Thus, the rate of primary hip replacement was slightly higher and the rate of hip revision was slightly lower than the corresponding rates in Sweden in general (138 and 16, respectively, see Background). During the years covered by this thesis the annual rate of hip revisions in northeast Scania ranged from 12 to 16 (mean 14) per 100,000 inhabitants.

Table 1. All hip revisions performed from 1994 to 1999 at the Department of Orthopedics in Hässleholm. 144 hips (139 patients) were revised with impacted morselized allograft bone and cement and 10 hips (10 patients) were revised with conventional cementing technique

Year	Allograft bone revision	Conventionally cemented revision	Reason for conventional cementing technique
1994	19	1	Expected short survival
1995	29	0	-
1996	23	1	Comminuted femoral fracture
1997	28	2	1 socket dislocation in an old and senile patient 1 deep infection in a patient with only socket revision
1998	20	1	Comminuted femoral fracture
1999	25	5	1 stem fracture in a patient with prior allograft revision at another hospital 1 socket dislocation in a hip with acetabular dysplasia 3 recurrent femoral head dislocations in 1 alcoholic and 2 old and senile patients
Total	144	10	

Table 2. Inclusion periods for the 139 patients (144 hips) in the nine studies



From January 1994 to December 1999, 144 hip revisions with impacted morselized allograft bone and cement were performed at our orthopaedic department. The 144 revisions (83 involving right hip) were done on 139 patients (68 women) aged 41 to 91 years (mean 73 years) (Table 1). Each of these hip revisions was included in at least 1 of the 9 studies in this thesis (Table 2). 123 of the 144 hips were revised for the first time; the time interval between the primary replacement and revision ranged from 3 months to 22 years (mean 10 years). 16 hips were revised for the second time, 3 for the third time, and 2 hips were revised for the fourth time. The time interval between the latest and current revision ranged from 4 years to 18 years (mean 9 years). In 13 of the 144 hips only the stem was revised and in 36 hips only the socket was revised. In 1 hip with both components revised, allograft bone was used only in the femur. Thus, 108 stems and 130 sockets were revised with impacted morselized allograft bone and cement. Aseptic loosening was by far the most common indication for revision (Table 3). The need for revision was discovered during a routine follow-up of hip replacement in 61 of the 144 hips, during a scheduled visit

Table 3. Indication for allograft bone revision in 144 hips (139 patients)

Aseptic loosening of both the stem and the socket	60
in combination with femoral shaft fracture	2
Aseptic loosening of the stem only	11
in combination with femoral shaft fracture	3
in combination with damaged socket	4
Aseptic loosening of the socket only	31
in combination with damaged socket	2
Infection diagnosed preoperatively and verified with tissue cultures [a] at surgery	11
Low-virulent infection diagnosed with routine tissue cultures [a] at surgery	17
in combination with femoral shaft fracture	1
Recurrent dislocation	1
Conversion of hemiarthroplasty	1

[a] According to Kamme and Lindberg (1981)

arranged after telephone call from the patient in 40, during an emergency patient visit at the department in 13, or after referral from a primary care physician in 30 hips. Of the 144 hip revisions, 29 were performed by one surgeon, 90 by a second surgeon and 25 by a third surgeon.

During the study period 10 other hips were revised at our department but excluded from the revision technique studied because of expected inability to follow instructions for restricted weight bearing after revision, expected survival of less than 1 year and, expected technical difficulties because of dysplasia of the acetabulum and comminuted femoral fracture (Table 1).

Surgical technique

All 144 hip revisions with impacted morselized allograft bone and cement (108 stems and 130 sockets) were performed in an operating theater within a Charnley-Howarth enclosure (Omniflow, Nr. Chorley, England), i.e. in ultra clean environmental air (less than 10 colony forming units/m^3) (Lidwell et al. 1982, Lidwell 1988) (Figure 9). Body-exhaust system was not used. A posterolateral approach without trochanteric osteotomy was used in all revisions. In almost all cases, except preoperatively known infected cases, an autotransfusion system (AT1000 Automatic, Electromedics, Englewood, Colorado) was used to collect and return blood during surgery.

Cloxacillin and low-molecular-weight heparin were given for prophylaxis against infection and thrombosis. Fresh-frozen femoral heads were morselized using the Tracer Bone Mill with a medium-sized cutter and a hand crank (Tracer Designs, Santa Paula, California). This technique produced allograft bone chips of approximately 3-mm size (Figure 10). Prior to morselization, the femoral heads were thawed in a warm (50–60 °C) saline solution for approximately 20 minutes and cleaned from soft tissue and cartilage debris. The bone chips were compressed in a cotton cloth for delipidization. Vacuum-mixed prechilled Palacos bone cement containing gentamycin was used in all revisions (Schering-Plough International, Kenilworth, New Jersey, USA) and was inserted with a cement gun and (in the femur) a narrow nozzle.

After removing the prosthetic components intended to be revised and the cement the surgical manual for the X-change revision instruments system was followed (Figure 11).

Standard collarless tapered and polished Exeter Universal stems (Howmedica International, London, England) were used in 94 of the 108 hips with stem revision. In 13 hips a longer stem was used because of fracture or osteolysis at or just below the level where the tip of a standard Exeter stem would have been positioned. The aim was to position the tip of the stem below the level of the lesion by a distance of at least twice the width of the femoral canal (Callaghan et al. 1985, Dennis et al. 1987, Rubash and Harris 1988, Klein and Rubash 1993). Long Exeter stems were, however, not available until late in the study period when it was used in 2 hips. Before that long CPT stems (Zimmer, Warsaw, Indiana) were used in 8

Figure 9. Operating theater with ongoing hip replacement surgery in an ultra clean environment.

Figure 10. Morselization of femoral heads in a bone mill.

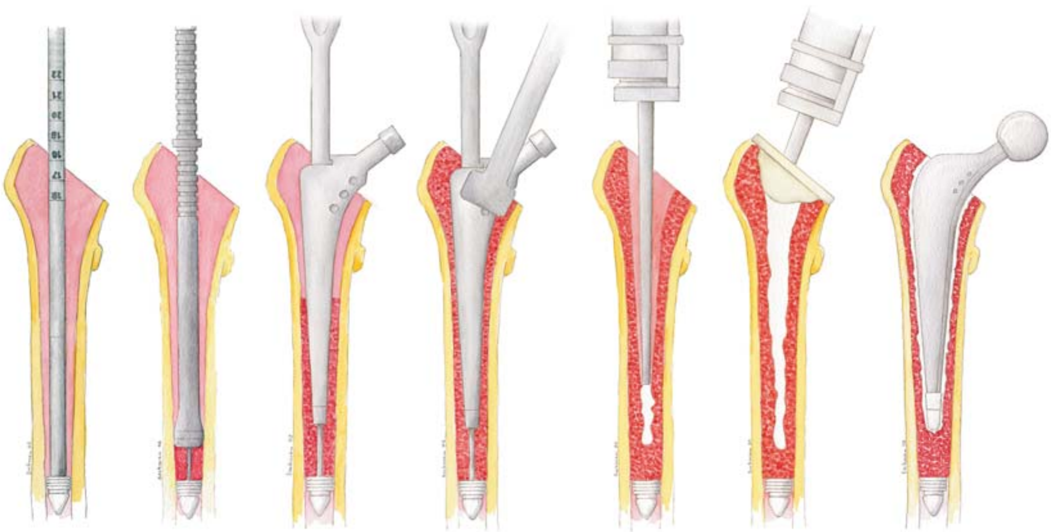


Figure 11. Figures of the X-change revision instruments system for femoral revision. From left: plug and guide insertion, distal impaction of morselized allograft bone, phantom impaction for neo-medullary femoral canal, proximal impaction, cement insertion, cement pressurization, and the stem cemented in the neo-medullary canal (the wings removed from the centralizer).

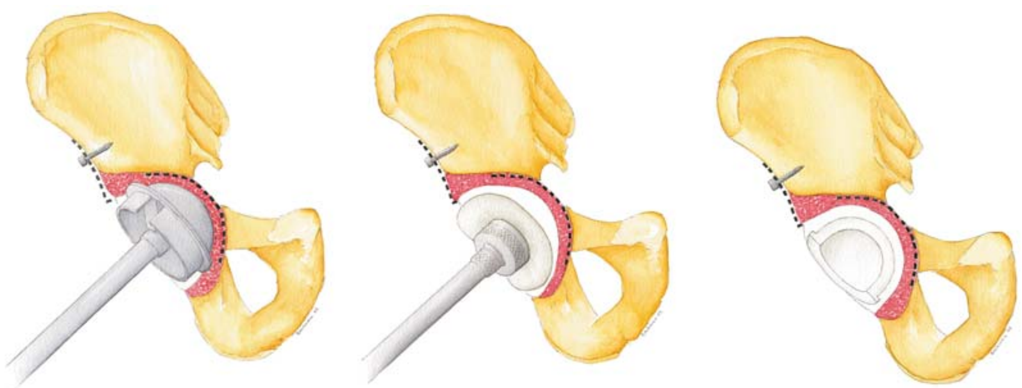


Figure 12. Figures of the X-change revision instruments system for socket revision. From left: allograft bone impaction after reconstruction of bottom and lateral rim of the acetabulum, cement inserted and pressurized, and socket cemented in the allograft bone.

hips with the specific graft impaction instruments developed for this prosthesis (Weidenhielm et al. 1994), and long Lubinus SPII stems (Waldemar Link, Hamburg, Germany) were used in 3 hips with the impaction performed with the trial prosthesis. A small Lubinus stem was used in 1 patient with a narrow femoral canal. When the distal femoral plug slipped off the femoral guide rod during impaction, the plug was temporarily fixated with a Kirschner wire inserted through the femur distal to the plug (Northmore-Ball et al. 1991).

Low-profile standard Exeter sockets (Howmedica International, London, England) were used in 112 of the 130 hips with socket revision (Figure 12). In 18 of the 36 hips with only socket revision, no Exeter sockets corresponding to the existing femoral components were available, and therefore sockets from other manufacturers were used. In 15 hips Lubinus concentric sockets without snap-fit were used and in 3 hips Scanhip sockets (ScandiMed, Sjöbo, Sweden) were used. In 5 of the 36 hips with only socket revision the stem was temporarily removed to improve exposure of the acetabular region. After revision of the socket the stem was recemented in the intact cement mantle in the femur (Lieberman et al. 1993) (Figure 13).

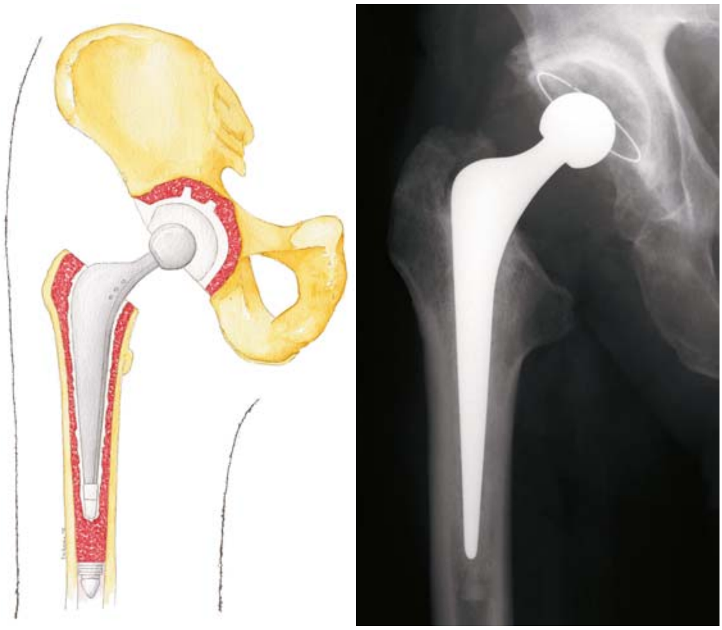


Figure 13. Illustration and radiograph of a hip revision with impacted morselized allograft bone and cemented Exeter prosthesis.

Additional femoral devices

Various types of meshes such as the Vitallium Mandibular, the Wire Mesh, and the X-change Revision Mesh (Howmedica International, London, England), and the Protek Steel Gauze (Sulzer Medica, Stockholm, Sweden) were used to reconstruct the femoral canal facilitating containment of the allograft bone in 18 hips.

Various types of cerclage wires and braided cables were used in 48 femurs to keep meshes in place, to prevent femoral fracture during graft impaction and stem insertion, or to fixate fractures. After the first 10 cases only cerclage wires and braided cables with torque-controlling devices monitoring appropriate tension and preventing over-tightening were used (Wroblewski Spring Compression Wire System, Thackray, Leeds, England and Dall-Miles Cable Grip System, Howmedica International, London, England).

Various types of femoral plates such as the dynamic compression femoral plate (Stratec Medical, Stockholm, Sweden), the Dall-Miles plate (Howmedica International, London, England) with or without cerclage wires or braided cables, and the Hartmann trochanter and compression plate (Waldemar Link, Hamburg, Germany) were used to fixate femoral fractures in 8 hips during revision. In addition, Partridge Cerlene plates with Cerlene straps (Partridge and Evans 1982) (Howmedica International, London, England) were used in 1 femoral revision.

For treatment of the femoral fractures that occurred postoperatively dynamic compression femoral plates as described above were used in 4 hips and upside-down applied long dynamic compression hip screw system plates (Smith & Nephew Richards, Memphis, Tennessee) in 4.

Additional acetabular devices

Various types of meshes such as the Cement restrictor (Thackray, Leeds, England), the Vitallium Mandibular Mesh, the Wire Mesh, and the X-change Revision Mesh (Howmedica International, London, England), and the Protek Steel Gauze (Sulzer Medica, Stockholm, Sweden) were used to reconstruct the bottom of the acetabulum facilitating containment of the allograft bone in 16 hips.

Various types of reconstruction plates such as the 3.5-mm AO Reconstruction Plate (Stratec Medical, Stockholm, Sweden), the X-change Rim Mesh, and the Kerbol Acetabular Shell (Howmedica International, London, England) were used to reconstruct the acetabular walls and rims facilitating containment of the allograft bone in 8 hips.

In 1 hip in which the femoral head could not be retained in the socket a stabilization wedge (DePuy, Leeds, England) was fixated with screws on the posterior edge of the socket (Olerud and Karlström 1985, Falkenberg-Nielsen and Andersen-Ranberg 1989).

Methods

Patient outcome and clinical assessment

Nottingham Health Profile questionnaire

The Nottingham Health Profile (NHP) patient-administered questionnaire was used preoperatively and postoperatively to measure the generic patient outcome (Hunt et al. 1991, Wiklund 1992, Garellick et al. 1998). The NHP consists of 6 scales (pain, energy, sleep, physical mobility, emotional reaction, and social isolation). Each scale has 3 to 8 items with "yes" and "no" response choices. The responses to the items in each scale are weighted and summed to give a final scale score ranging from 0 (best) to 100 (worst health).

The pain scale consists of 8 items inquiring about the presence or absence of constant pain, unbearable pain, pain at night, and pain on walking, changing position, sitting, standing, and going up and down stairs.

The energy scale consists of 3 items inquiring about tiredness, effort, and energy.

The sleep scale consists of 5 items inquiring about difficulty to sleep and need for medication.

The physical mobility scale consists of 8 items inquiring about ability to walk at all and difficulty or need for assistance to walk about outdoors, walk about indoors, get up and down stairs, stand for a long time, dress, bend, and reach for things.

The emotional reaction scale consists of 9 items concerning various expressions of mental health.

The social isolation scale consists of 5 items concerning social interaction.

Charnley categories

For the clinical assessment the patients were classified preoperatively and postoperatively into categories A, B and C according to Charnley (1979).

Charnley category A – The patient is physically fit in all respects relating to function, with allowance for age, and without any defect other than the one hip affected by arthritis.

Charnley category B – The patient has both hips affected but is otherwise physically fit for age and no other factor interfering with function exists.

Charnley category C – The patient has other conditions directly impairing walking (i.e. the patient's function would still be limited if the hips were normal).

The Charnley scores

The Charnley scores were used preoperatively and postoperatively for clinical grading of pain, walking ability and range of hip motion (Charnley 1979). The Charnley scores have 6 values ranging from 1 (worst) to 6 (best).

Pain

1. Severe, spontaneous pain.
2. Severe pain on attempting to walk, prevents all activity.
3. Pain is tolerable, permits limited activity.
4. Pain only after some activity, disappears quickly with rest.
5. Slight or intermittent pain on starting to walk, becomes less with normal activity.
6. No pain.

Walking ability

1. None (bedridden) or few yards with 2 sticks or crutches.
2. Very limited in time and distance with or without sticks.
3. Limited with 1 stick (<1 hour), difficult without a stick, able to stand long periods.
4. Long distances with 1 stick, limited without a stick.
5. No stick but a limp.
6. Normal.

Range of motion (sum of all the ranges of movements: flexion, abduction-adduction and rotation)

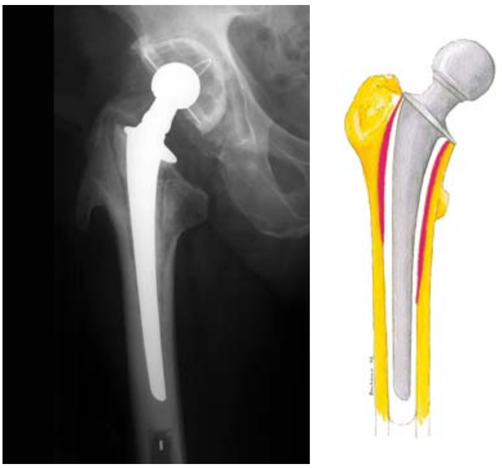
1. 0–30º
2. 30–60º
3. 60–100º
4. 100–160º
5. 160–210º
6. >210º

Radiographic evaluation

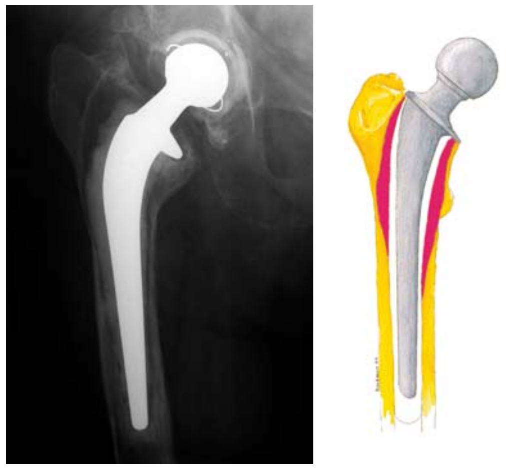
Bone stock deficiency

Bone stock deficiency was classified according to Gustilo and Pasternak (1988) (Figure 14 and 15).

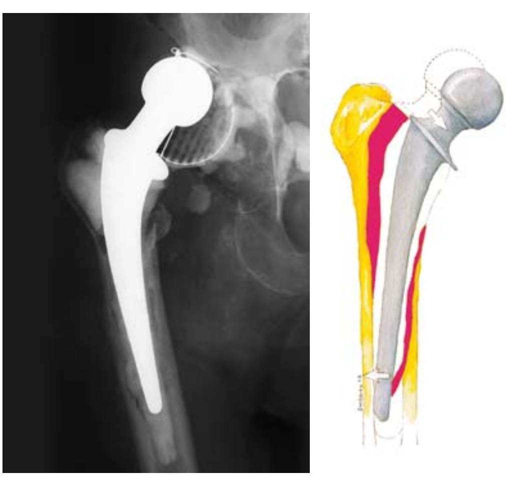
Figure 14. Femoral bone stock deficiency types I to IV according to Gustilo and Pasternak (1988).



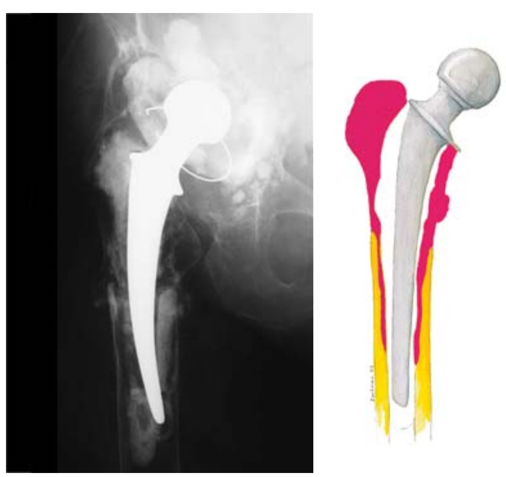
Type I. Bone loss with minimal endosteal or inner cortical bone loss, i.e. loosening at the cement-metal-bone interface or a broken stem.



Type II. Proximal femoral canal enlargement with cortical thinning of 50% or more, and sometimes there is a lateral wall defect with an intact circumferential wall. The most important difference between Type I and II is the loss of almost all the trabecular bone in Type 2.

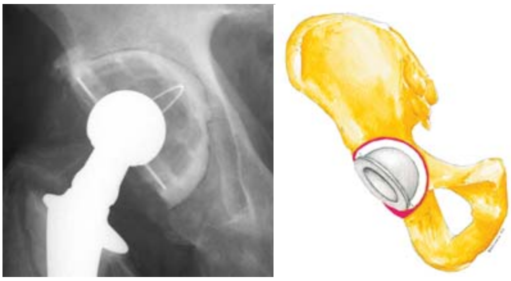


Type III. Posterior-medial wall defects involve the lesser trochanter indicating instability.

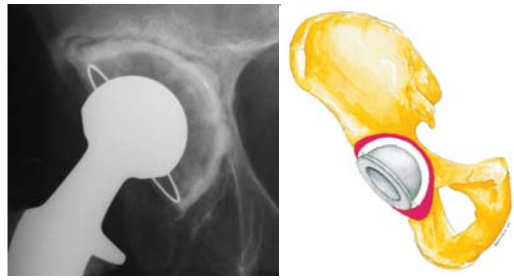


Type IV. Total circumferential loss of bone at varying distances below the lesser trochanter.

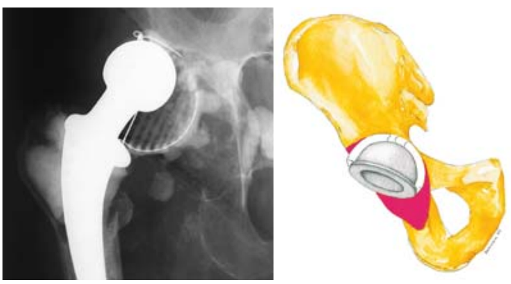
Figure 15. Acetabular bone stock deficiency types I to IV according to Gustilo and Pasternak (1988).



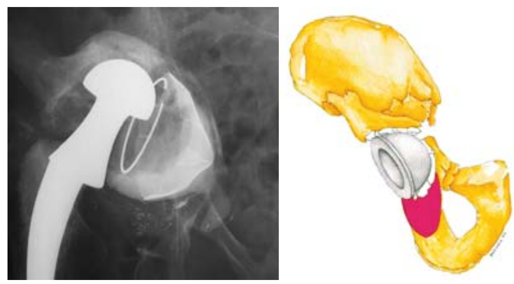
Type I. Minimal enlargement of the acetabular wall and loosening at the cement-prosthesis interface.



Type II. Acetabular bone loss with marked enlargement and thinning of the acetabular wall but no wall defect and loosening at the cement-bone interface.



Type III. Acetabular bone loss with local quadrant wall defects: anterior, posterior, superior, or central.



Type IV. Massive global collapse involving two or more acetabular walls.

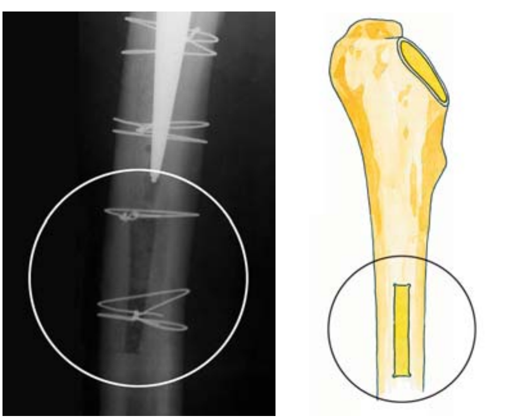


Figure 16. Radiograph and illustration of deliberate femoral cortical window.

Figure 17. Radiograph and illustration of incidental femoral perforation.

Deliberate femoral cortical window and incidental femoral perforation

All femoral cortical windows that were deliberately made during surgery were recorded (Figure 16). All incidental femoral perforations were recorded and also sought for on radiographs performed after revision (Figure 17).

Femoral fracture classification

Femoral fractures that occurred during surgery or postoperatively were classified into: fractures of the greater trochanter, proximal fractures and diaphyseal fractures. The proximal and the diaphyseal fractures were divided into complete fractures and incomplete fractures (vertical cracks) according to Schwartz et al. (1989) (Figure 18).

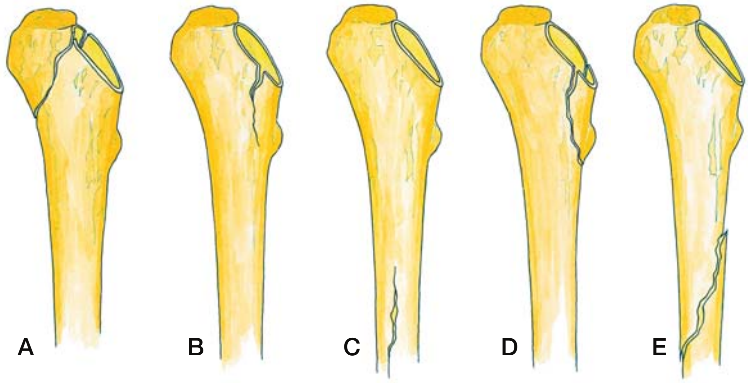


Figure 18. Femoral fractures classified according to Schwartz et al. (1989). (A) fracture of the greater trochanter, (B) proximal vertical crack, (C) diaphyseal vertical crack, (D) complete proximal fracture, (E) complete diaphyseal fracture.

Quality of allograft bone packing

The quality of allograft bone packing was classified according to Gie et al. (1993a) into excellent, good, fair, poor and defective.

Cement mantle and cement beyond the tip of the stem

Periprosthetic cement mantle continuity and cement beyond the tip of the stem were assessed.

Stem position

Stem position was considered as neutral when the prosthetic alignment was up to ±3° but as varus (-) or valgus (+) when the prosthetic alignment was ≥4°, according to Eldridge et al. (1997a).

Allograft bone appearance

Allograft bone appearance was classified according to Gie et al. (1993a) and Linder (2000) and presented in zones according to Gruen et al. (1979) for femur and according to DeLee and Charnley (1976) for acetabulum (Figure 19).

No change. Completely unchanged graft findings as compared to the first postoperative radiographs.

Trabecular incorporation. Any change in the structure of the graft as compared to the first postoperative radiographs but not fulfilling the very strict criteria for trabecular remodeling.

Trabecular remodeling. The graft has changed into a pattern in harmony with the adjacent host bone.

Cortical healing (only for femur). A thinned-out cortex or a cortex with localized endosteal erosions regaining a normal cortical structure and thickness for the region in question.

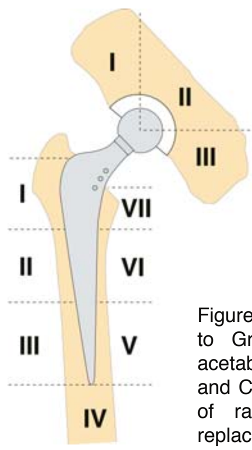


Figure 19. Zones of femur according to Gruen et al. (1979) and of acetabulum according to DeLee and Charnley (1976) for description of radiographic analysis in hip replacements.

In both femur and acetabulum occurrence of allograft bone resorption was also recorded.

Radiolucent lines

Periprosthetic radiolucent lines were classified, according to the protocol used by the inventors in Exeter, into line width of <1 mm, 1–2 mm, and >2 mm and presented in zones according to Gruen et al. (1979) for femur and according to DeLee and Charnley (1976) for acetabulum.

Femoral dimension

Femoral dimension was measured on the first postoperative radiographs and on the 5-year radiographs using a slide caliper according to Karlsson et al. (1996). The width of the medullary cavity (endosteal diameter) and the width of the femoral bone (periosteal diameter) 1 cm below the tip of the stem were measured and the periosteal diameter 1 cm below the lesser trochanter was also measured.

Radiostereometric analysis

To enable radiostereometric analysis (RSA) of the prosthetic movements according to the method described by Selvik (Selvik 1989, Kärrholm et al. 1997), 0.8 mm tantalum markers were implanted during hip revision in the greater and lesser femoral trochanters, tuber ischii, the acetabular roof and the socket (Figure 20 and 21). When stem migration within the cement mantle was planned to be studied, tantalum markers were also inserted in the medial-proximal aspect of the cement.

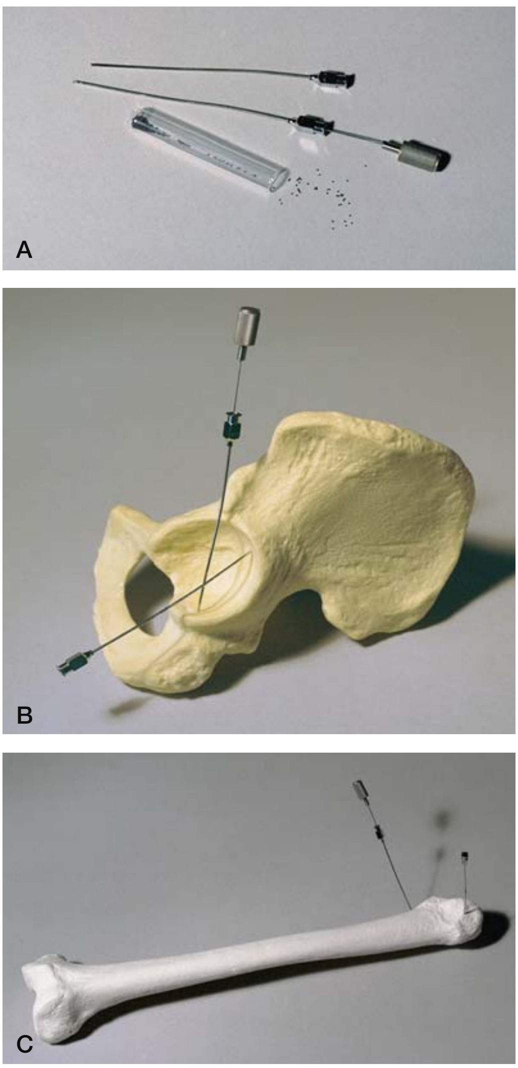


Figure 20. (A) Instruments for insertion of tantalum markers. (B) Insertion of markers in the pelvis. (C) Insertion of markers in the femoral trochanters.

Figure 21. Radiograph with tantalum markers in the pelvis, socket, and trochanters.

Each RSA examination was performed with the patient in the supine position by using two 40° angulated roentgen tubes facilitating simultaneous exposures of the hip with the implanted 0.8-mm tantalum markers, and a combined reference and calibration device with similar tantalum markers placed at known positions, on two separate uniplanar films. (Kärrholm et al. 1997) (Figure 22). The two-dimensional distances between the images of the tantalum markers on the two films provided the input data for computerized conversion to a three-dimensional coordinate system using the Kinema software (RSA BioMedical Innovations AB, Umeå, Sweden) (Figure 23). Thereafter, migrations of the stem, and migrations and rotations of the socket could be calculated. The stem migrations were calculated as point motion, i.e. displacement of the center of the prosthetic head relative to the femoral bone. Rotations cannot be calculated for a point. The migrations and rotations of the socket were calculated as segment motion, i.e. displacement of the socket body relative to the acetabular bone. The postoperative RSA index examination was performed before the patient was mobilized.

The accuracy of the RSA setup was calculated by repeat examinations of the hips at the RSA index examinations. The migrations (stems and sockets) and the rotations (sockets) between these double examinations, expected to be zero within pairs, and the standard deviation (SD = $\sqrt{\Sigma \frac{d^2}{(n-1)}}$) for each direction of the migrations and the rotations were calculated. By using Student's t-distribution, the 99% confidence limits for the smallest significant migrations (stems and sockets) in the proximal-distal direction, the medial-lateral direction and the posterior-anterior direction were calculated. Likewise, the smallest significant rotations (sockets) for anteversion-retroversion (around the longitudinal axis), anterior-posterior rotation (around the transverse axis), and abduction-adduction (around the sagittal axis) were calculated. Measured migration values and rotation values above these calculated significant levels (accuracy) were considered as significant prosthetic movements, but measured values below these levels were classified as non-significant, i.e. no detectable prosthetic movement in the individual case. The accuracy was calculated in each of the RSA studies IV, V, VI and VII, but in the RSA studies II, III and VIII the accuracy calculated in study IV and study VI was used.

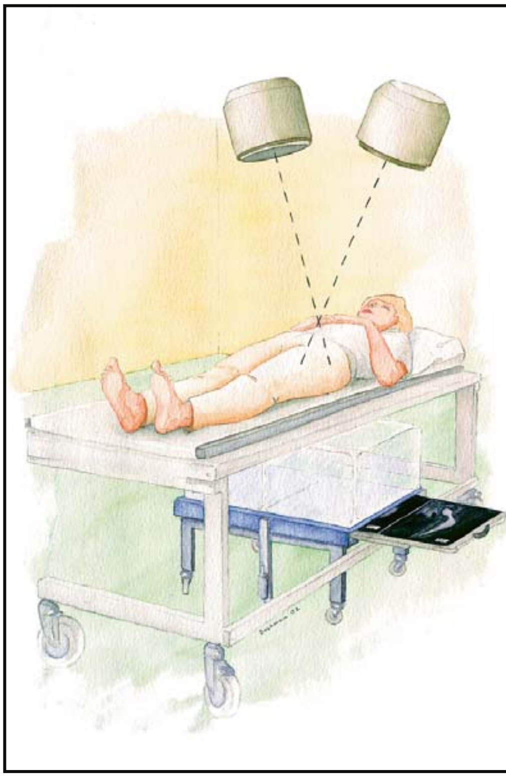


Figure 22. RSA examination with two 40° angulated roentgen tubes and combined reference and calibration device.

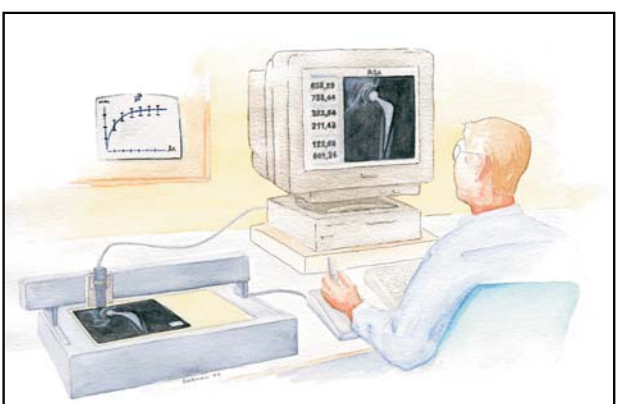


Figure 23. RSA scanning and analysis.

Summary of papers

Paper I. Quality-of-life outcomes in hip revision arthroplasty with impacted morselized allograft bone and cement: comparison with primary arthroplasty

Background

Outcomes of hip revision have been considered to be inferior to those of primary replacement with regard to clinical improvement and patient satisfaction. The purpose of this study was to assess with a validated outcome instrument quality of life in hip revision with impacted morselized allograft bone and cemented Exeter prosthesis compared to primary hip replacement.

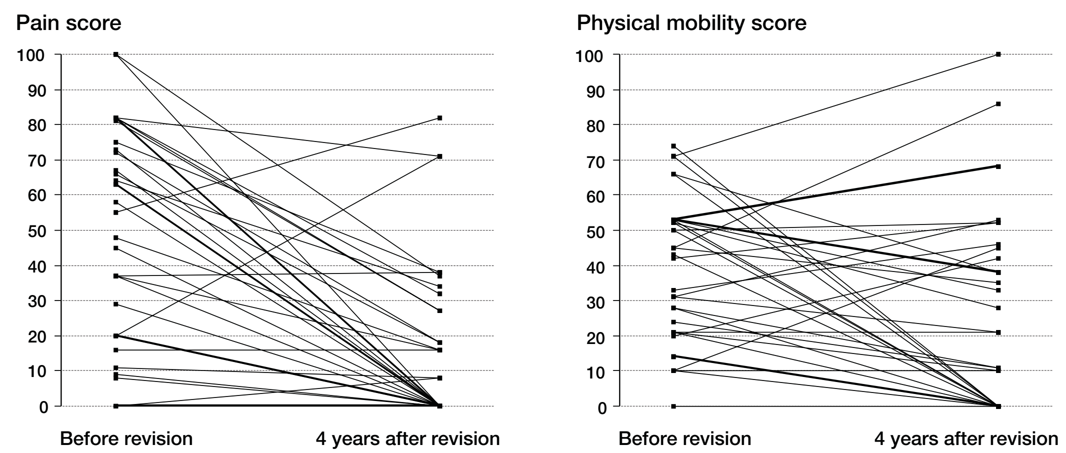
Patients and methods

49 first-time hip revisions (40 stems and 47 sockets) were performed on 24 women and 25 men aged 57 to 91 years (mean 74 years). All hips had had the primary replacement because of osteoarthrosis. The Exeter prosthesis was used in all revisions except for 5 sockets. 61% of the patients were overweight. Both stem and socket were revised in 38 hips, the socket only in 9 and the stem only in 2. The diagnosis was aseptic loosening in all revisions. The patients were evaluated with the Nottingham Health Profile (NHP) generic outcome instrument and Charnley scores preoperatively and yearly to 4 years after surgery.

For comparison, 159 patients in the 4th year after a primary cemented hip replacement performed because of osteoarthrosis were offered the NHP questionnaire by mail. 144 patients (79 women and 65 men) aged 44 to 87 years (mean 70 years), with 98 Lubinus SPII prostheses and 46 Exeter prostheses, answered the questionnaire.

Results

- The NHP scores revealed improvement in most health dimensions at 6 months after revision; repeated measures analysis showed maintained improvement in the NHP scores for pain (Figure), physical mobility (Figure), sleep, and energy.
- 4 years after revision the magnitude of health improvement was large for pain, moderate for physical mobility, small to moderate for sleep, and small for energy.



Individual patient scores for the Nottingham Health Profile's pain and physical mobility scales before and 4 years after hip revision. Scale scores range from 0 (best) to 100 (worst). Bold line indicates 2 patients with identical scores (Paper I).

Table. The scores for the Nottingham Health Profile (NHP) scales 4 years after hip revision and during the fourth year after primary hip replacement, stratified according to Charnley category

	Revision arthroplasty		Primary arthroplasty	
NHP scale [a]	A or B [b] (n 21)	C [b] (n 15)	A or B [b] (n 60)	C [b] (n 84)
Pain	8 (13)	30 (27)**	6 (15)	30 (27)***
Physical mobility	11 (18)	48 (24)***	11 (19)	35 (22)***
Energy	7 (19)	51 (44)**	13 (24)	40 (40)***
Sleep	12 (18)	22 (21)	12 (22)	27 (29)**
Emotional reaction	3 (7)	14 (16)*	3 (8)	13 (23)**
Social isolation	4 (11)	10 (11)	4 (11)	9 (21)

[a] The NHP scores shown as mean (SD); score ranges from 0 (best) to 100 (worst).
[b] Category A or B (hip disease only, normal or prosthetically replaced contralateral hip); Category C (multiple joint disease or other disease impairing walking ability).
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (category C compared to category A or B)

- The NHP mean scores for the emotional reaction and social isolation scales were low before revision, implying no impairment in these health dimensions for most of the patients (consequently no substantial score improvement would be expected).
- The mean 4th-year postoperative NHP scores for the primary hip replacement group did not differ significantly from the mean 4-year postoperative NHP scores for the revision group in any of the scales (even after adjustment for sex, age, and Charnley category) (Table).
- Patients classified as Charnley category C had worse NHP mean scores than patients classified as category A or B (Table).
- The correlation between the NHP and Charnley scores for pain was moderate preoperatively and weak at 4 years after revision.
- The correlations between the NHP scores for physical mobility and the Charnley scores for walking ability were moderate both preoperatively and at 4 years postoperatively after revision.

Paper II. Radiostereometric analysis in hip revision surgery – optimal time for index examination. 6 patients revised with impacted allografts and cement followed weekly for 6 weeks

Background

RSA has become the gold standard for measuring prosthetic kinematics in joint replacement surgery. Early migration of prosthetic components relative to the RSA index examination after surgery is presumed to be a predictor of future loosening. Many RSA studies have, however, overlooked the potential of migration occurring during the first days or weeks between surgery and the RSA index examination (Table). The purpose of this study was to investigate with RSA the initial prosthetic migration pattern from the 1st day after surgery and before mobilization of the patient in hip revisions with impacted morselized allograft bone and cemented Exeter prosthesis.

RSA reports dealing with hip replacements

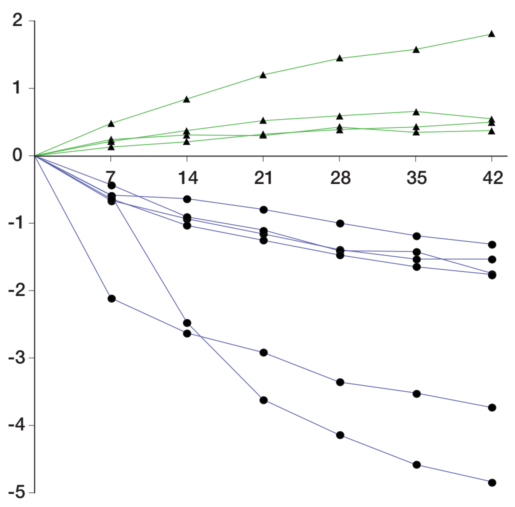
Year	Author	Index examination	Components studied	Primary/ revisions
1990	Snorrason and Kärrholm	"1–3 weeks (all patients)"	Both	Revisions
1991	Nistor et al.	"as soon as practical (6–11 days postoperatively)"	Stems	Primary
1992	Franzén et al.	"at 1 week"	Stems	Revisions
1993	Franzén et al.	"1 week"	Sockets	Revisions
1994a	Önsten et al.	"usually within 2 weeks"	Sockets	Primary
1994b	Önsten and Carlsson	"within 1 week"	Sockets	Primary
1994	Kärrholm et al.	"1 day to 2 months"	Stems	Primary
1995	Franzén et al.	"1 week"	Stems	Revisions
1995a	Önsten et al.	"at 1 week"	Stems	Primary
1995b	Önsten et al.	"within 10 days"	Stems	Revisions
1995	Malchau et al.	"4–6 days"	Stems	Primary
1996	Önsten et al.	"at about 1week"	Stems	Primary
1996	Nivbrant et al.	"within the first 11 days"	Sockets	Revisions
1997	Nivbrant et al.	"within the first week"	Sockets	Revisions
1999	Kärrholm et al.	"at 5 to 10 days"	Stems	Revisions
1999	Alfaro-Adrián et al.	"at 1 to 2 weeks"	Stems	Primary

Patients and methods

6 first-time hip revisions (6 stems and 5 sockets) with the Exeter prosthesis were performed on 2 women and 4 men aged 47 to 76 years (mean 68 years). The diagnosis was aseptic loosening in 4 revisions and low-virulent infection (diagnosed with routine tissue cultures at surgery) in 2 revisions. All revisions were classified as having bone stock deficiency type II. The prosthetic migration was followed with RSA on every 7th day for 6 weeks. The RSA index examination was performed before mobilization on the 1st day after surgery. After the index RSA free weight bearing was allowed.

Results

- All prosthetic components migrated in at least 1 direction.
- Considerable migration occurred during the 1st week after revision emphasizing the need for an early RSA index examination (Figure).



Distal migration of 6 stems (–mm), and proximal socket migration of 4 sockets (+mm) (1 socket showed no proximal migration) during 42 days after revision (Paper II).

- The migration decreased gradually in all directions (Figure).

Paper III. Early subsidence of the Exeter femoral stem within the cement mantle in primary arthroplasties and in revisions using impacted allografts and cement: a roentgen stereophotogrammetric analysis

Background

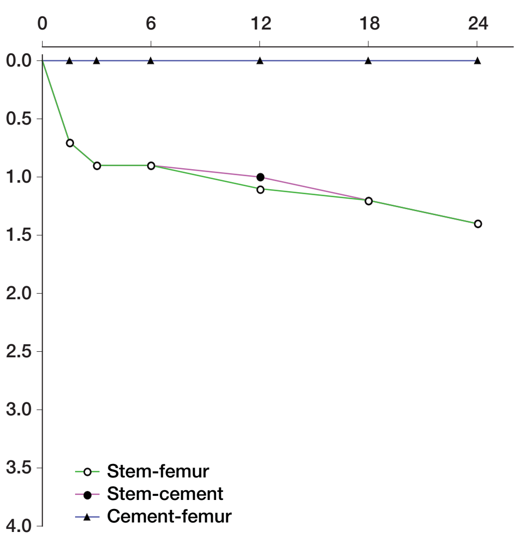
Investigators not involved in the development of the Exeter prosthesis have questioned whether stem migration to any extent can take place within the cement mantle. The purpose of this study was to assess with RSA whether the collarless, double tapered and polished Exeter stem subsided within the cement mantle and/or the stem-cement beam subsided relative to the femur in primary hip replacement and in revision with impacted morselized allograft bone and cement.

Patients and methods

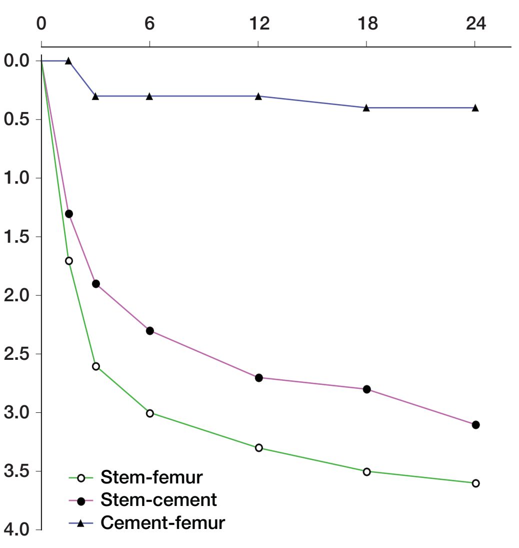
To evaluate Exeter stem migration within the cement mantle tantalum markers were inserted in the medial-proximal aspect of the cement in 5 primary hip replacements and in 6 revisions. The diagnosis was osteoarthrosis in all primary replacements and aseptic loosening in all revisions. In 2 primary arthroplasties and in 2 revisions with bone stock deficiency type II the tantalum markers in the cement could be imaged for RSA follow-up of the stem and cement migration during 2 years. The index RSA examination was performed on the 2nd day after surgery in 3 hips and on the 3rd day in 1 hip. After the index RSA restricted weight bearing was practiced for 3 months in the revisions.

Results

- All stems both in the primary replacements and the revisions subsided within the cement mantle (Figures).
- In the revisions there was an additional subsidence of the cement relative to the femur (Figure).



Distal stem migration (mm) in a cemented Exeter primary hip replacement during 24 months (Paper III).



Distal stem and stem-cement beam migration (mm) in a hip revision with morselized allograft bone and cemented Exeter prosthesis during 24 months. (Paper III).

Paper IV. Results of hip revision using the Exeter stem, impacted allograft bone and cement (2-year follow-up)

Background

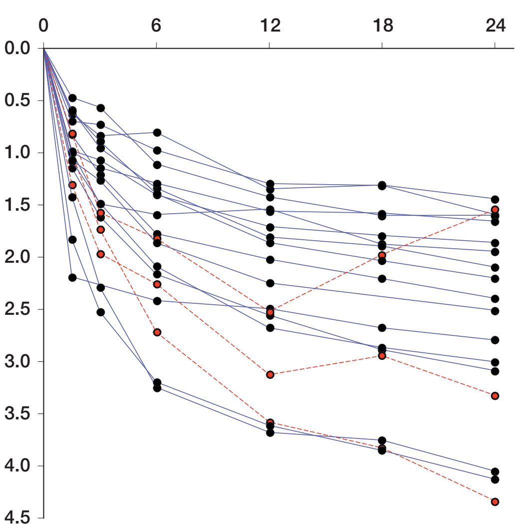
For a decade impacted morselized allograft bone and cement has been advocated to solve the problem of bone stock deficiency in stem revisions. The stem movement over time and its implications for the result of this surgical procedure is in part still enigmatic and needs further elucidation. The purpose of this study was to investigate with RSA the migration pattern of the Exeter stem during the first 2 years after hip revision with impacted morselized allograft bone and cement.

Patients and methods

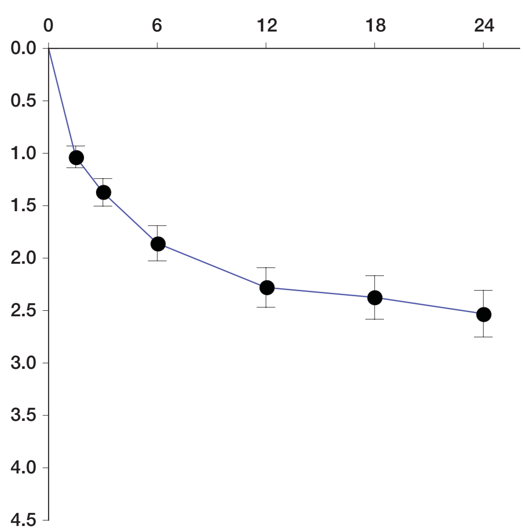
18 first-time stem revisions with the Exeter stem were performed in 7 women (1 bilateral) and 10 men aged 60 to 82 years (mean 74 years). All hips had had the primary arthroplasty because of osteoarthrosis. The diagnosis was aseptic loosening in all revisions. Bone stock deficiency was classified as type I in 6 revisions, type II in 9, and type III in 3. The stem migration was followed with RSA for 2 years and the clinical result was assessed with Charnley scores. After the index RSA (median 2 days after surgery) restricted weight bearing was practiced for 3 months.

Results

- Stem migration was most pronounced early after revision (Figures).
- 6 of the 18 stems continued to migrate above RSA accuracy in at least one direction between 1.5 and 2 years after revision (Figure).
- The Charnley scores for pain and walking ability improved in most patients.



Distal migration (mm) of 18 stems during 24 months. Dotted lines represent stems still migrating above accuracy between 1.5 and 2 years (Paper IV),



Distal mean (SE) migration of 18 stems during 24 months (Paper IV),

Paper V. Hip revision arthroplasty using the Exeter stem, impacted morselized allograft bone and cement. A prospective and consecutive 5-year radiostereometric and radiographic study in 15 patients

Background

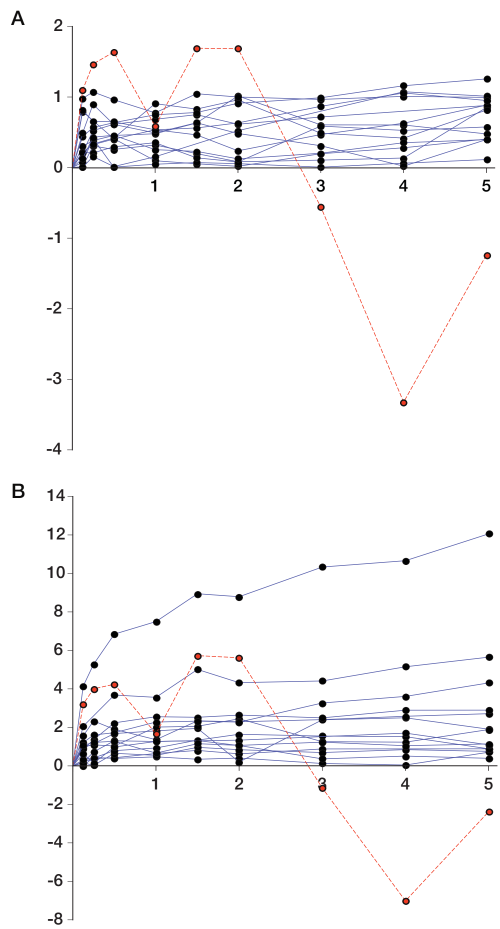
Prior conventional radiographic studies as well as our earlier RSA report on hip revision with impacted morselized allograft bone and cemented Exeter stem have disclosed that substantial stem subsidence can be expected during the initial years after surgery. According to the findings of our prior 2-year RSA follow-up all Exeter stems subsided 1.4 to 4.3 mm and one-third of the stems continued to migrate between 1.5 and 2 years. The purpose of this study was to continue investigating with RSA the course of this stem migration up to 5 years after surgery. Did early stem migration predict future migration? Did continued stem migration correlate with skeletal and prosthetic features assessed on conventional radiographs?

Patients and methods

15 of the 18 first-time stem revisions performed because of aseptic loosening in study IV could be followed with RSA, conventional radiography and Charnley scores for 5 years. There were 7 women (1 bilateral) and 7 men aged 60 to 82 years (mean 74 years). Bone stock deficiency was classified as type I in 6 revisions, type II in 7, and type III in 2. The radiographs were examined for quality of bone packing, cement mantle, cement beyond the tip of the stem, stem positioning, radiolucent lines and allograft bone appearance. The width of the femoral bone and of the medullary cavity measured on the initial postoperative radiographs and on the 5-year follow-up radiographs were compared.

Results

- No specific early migration pattern predicted future migration (linear regression analysis) (Figure).
- In 11 of the 15 stems marginal migration above RSA accuracy occurred in at least 1 direction between 2 and 5 years after revision without clinical deterioration.
- 1 stem was considered loose according to RSA (Figure). The patient was pain free and the radiographs 6 months postoperatively revealed a non-progressive radiolucent line in zone I.
- The total stem migration at 5 years after revision could not be correlated to bone stock deficiency, quality of bone packing, cement mantle defect, cement beyond the tip of the stem, stem positioning or radiolucent lines.
- The femoral width increased significantly below the lesser trochanter.
- The Charnley scores for pain and walking ability improved in most patients.
- In 9 of the 15 revisions radiographic signs of trabecular incorporation/remodeling of the graft was observed.



Migration (mm) of 15 stems during 5 years; medial-lateral (A) and posterior (B). Dotted line represents a wobbling stem considered loose according to RSA (Paper V)

Paper VI. Migration of the acetabular component after revision with impacted morselized allografts. A radiostereometric 2-year follow-up analysis of 21 cases

Background

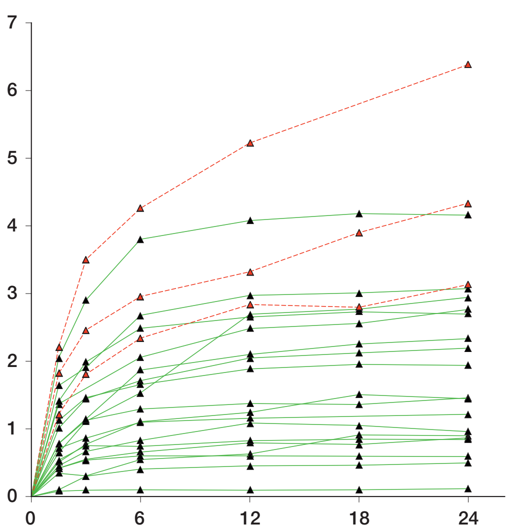
For a decade impacted morselized allograft bone and cement has been advocated to solve the problem of bone stock deficiency in socket revisions. The socket movement over time and its implications for the result of this surgical procedure is in part still enigmatic and needs further elucidation. The purpose of this study was to investigate with RSA the migration pattern of the Exeter socket during the first 2 years after hip revision with impacted morselized allograft bone and cement.

Patients and methods

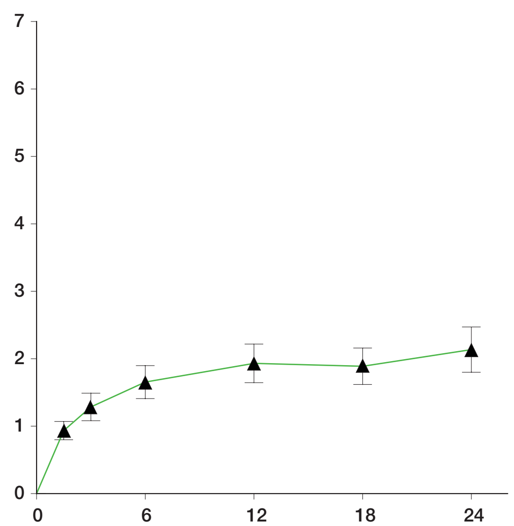
21 first-time socket revisions with the Exeter socket were performed in 10 women (1 bilateral) and 10 men aged 56 to 87 years (mean 74 years). All hips had had the primary replacement because of osteoarthrosis. The diagnosis was aseptic loosening in all revisions. Bone stock deficiency was classified as type I in 6 revisions, type II in 6, and type III in 9. The socket migration was followed with RSA for 2 years. After the index RSA (median 2 days after surgery) restricted weight bearing was practiced for 3 months.

Results

- All but 1 socket migrated in the proximal direction (Figures).
- The migration was most pronounced early after revision (Figures).
- 7 of the 21 sockets continued to migrate above RSA accuracy in at least one direction between 1.5 and 2 years after revision (Figure).



Proximal migration (mm) of 21 sockets during 24 months. Dotted lines represent sockets still migrating above accuracy between 1.5 and 2 years (Paper VI).



Proximal mean (SE) migration of 18 sockets during 24 months (Paper VI).

Paper VII. Five-year follow-up of socket migration patterns and loosening after Exeter hip revision with impacted morselized allograft bone and cement. A radiostereometric and radiographic analysis

Background

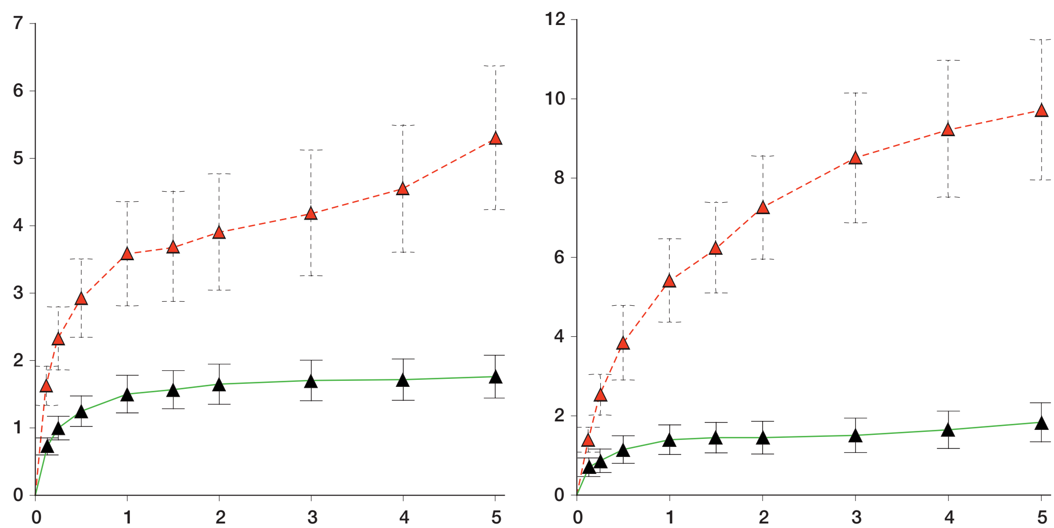
Prior conventional radiographic studies as well as our earlier RSA report on hip revision with impacted morselized allograft bone and cemented Exeter socket have disclosed that some socket migration can be expected during the initial years after surgery. According to our prior 2-year RSA follow-up all but 1 Exeter socket migrated 0.3 to 6 mm in at least one direction and one-third of the sockets continued to migrate between 1.5 and 2 years. The purpose of this study was to continue investigating with RSA the course of this socket movement up to 5 years after surgery. Did early socket migration and rotation predict future movements? Did continued socket movements correlate with skeletal and prosthetic features assessed on conventional radiographs?

Patients

17 of the 21 first-time socket revisions performed because of aseptic loosening in study VI could be followed with RSA, conventional radiography and Charnley scores for 5 years. There were 10 women (1 bilateral) and 6 men aged 56 to 81 years (mean 73 years). Bone stock deficiency was classified as type I in 5 revisions, type II in 6, and type III in 6. The radiographs were examined for radiolucent lines and allograft bone appearance.

Results

- No specific early migration or rotation pattern predicted future socket movements (linear regression analysis) (Figures).
- Migration and rotation in the 5 socket revisions with radiolucent lines >2 mm at 5 years was 2–3 times and 3–5 times, respectively, larger than in the 12 socket revisions with no radiolucent lines >2 mm (Figures).
- Allograft resorption occurred in at least 1 zone in the 5 socket revisions with a radiolucent line >2 mm at 5 years, but in 4 of these no progression of the radiolucent line was observed after the 2-year follow-up and there was no clinical deterioration or threat to bone stock necessitating rerevision.
- In 8 of the 17 sockets radiographic signs of trabecular incorporation/remodeling of the allograft bone were observed.
- The Charnley scores for pain and walking ability improved in most patients.



Mean (SE) proximal socket migration (mm) (left) and mean (SE) socket abduction-adduction (degrees) (right) during 5 years. The dotted line represents the 5 sockets with a radiolucent line >2 mm in at least 1 zone (according to DeLee and Charnley (1976)) and the unbroken line represents the 12 sockets with no radiolucent line >2 mm in width (Paper VII).

Paper VIII. Hip revisions with impacted morselized allografts: Unrestricted weight bearing and restricted weight bearing had similar effect on migration. A radiostereometry analysis

Background

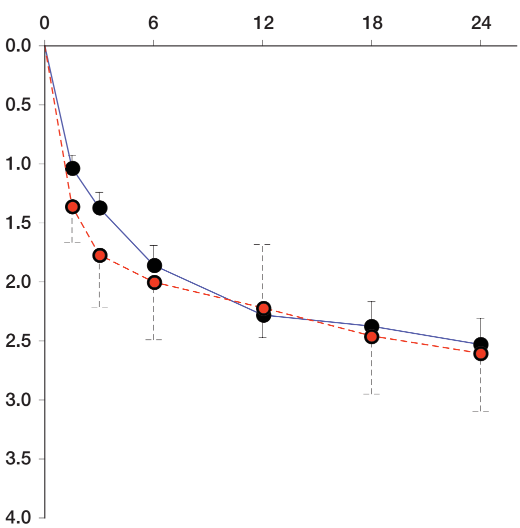
It has been unclear whether initial restriction of weight bearing is needed after hip revision with impacted morselized allograft bone and cement. The purpose of this study was to assess with RSA whether free weight bearing could be initiated immediately after hip revision with impacted morselized allograft bone and cemented Exeter prosthesis.

Patients and methods

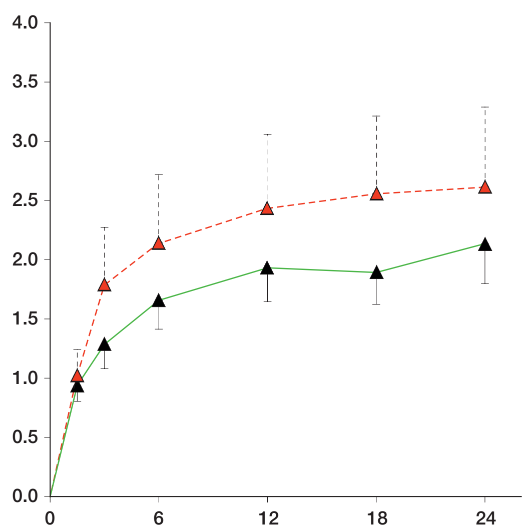
13 first-time hip revisions with 7 Exeter stems and 12 Exeter sockets were performed in 10 women and 3 men aged 61 to 84 years (median 73 years). The diagnosis was aseptic loosening in all revisions. All revisions were classified as having bone stock deficiency type II. The migration of the stems and the sockets was followed with RSA for 2 years. After the index RSA (median 2 days after surgery) free weight bearing was practiced as soon as this was felt comfortable by the patients. The migration rates were compared with the migration of the stems in study IV and the sockets in study VI, in which restricted weight bearing had been practiced for 3 months.

Results

- Free and restricted weight bearing after revision in hips with bone stock deficiency type II had similar effect on the migration rates of 6 of the 7 stems and all 12 sockets according to ANOVA test and Mann-Whitney U-test at a given time.
- 1 stem was considered loose according to RSA and radiography.



Mean (SE) distal stem migration (mm) during 24 months. The dotted line represents 6 stems (1 outlier excluded) in patients who were allowed free weight bearing and the unbroken line represents the 18 stems in study IV in patients who had restricted weight bearing for 3 months (Paper VIII).



Mean (SE) proximal socket migration (mm) during 24 months. The dotted line represents 12 sockets in patients who were allowed free weight bearing and the unbroken line represents the 21 sockets in study VI in patients who had restricted weight bearing for 3 months (Paper VIII).

Paper IX. Early complications in 144 consecutive hip revisions with impacted morselized allograft bone and cement

Background

Femoral fracture is the most frequently described serious early complication in hip revisions with impacted morselized allograft bone and cement. Fractures have been reported in 4 to 24% of hip revisions. Studies that specifically address the entire panorama of intraoperative and postoperative complications are lacking. The purpose of this study was to prospectively register and analyze all complications and technical incidents that occurred during surgery and within the 1st year after hip revision with impacted morselized allograft bone and cement.

Patients and methods

144 hip revisions (108 stems and 130 sockets) were performed on 68 women (3 bilateral) and 71 men (2 bilateral) aged 41 to 91 years (mean 73 years). The surgical procedure was a first-time revision in 123 hips. The reason for revision was aseptic loosening in 113 hips. All complications and technical incidents during surgery and within the 1st year were prospectively registered according to a standardized protocol including clinical and radiographic documentation.

Results

- Complications and technical incidents were recorded for 63 hips (63 patients). All but 1 thromboembolic complication could be handled without subsequent morbidity.
- Thromboembolic complications occurred in 4 patients with lasting morbidity in 1 patient.
- 21 femoral fractures occurred during revision; 17 were vertical crack fractures (11 proximal and 6 diaphyseal) and 4 were complete fractures (1 proximal and 3 diaphyseal).
- 10 femoral fractures occurred after revision (within 5 months); all were complete fractures (1 proximal and 9 diaphyseal). 8 diaphyseal fractures originated from cortical window or perforation.
- Concomitant disease (Charnley category C), large bone stock deficiency (type II and III) and cortical window or perforation during surgery increased the risk for femoral fracture (logistic regression analysis of risk factors).
- Other intraoperative complications were deliberately created femoral cortical window in 7 hips, incidental femoral perforation in 14, and isolated fracture of the greater trochanter in 8 hips.
- Other complications after surgery included femoral head dislocation in 9 hips, wound infection that required wound debridement in 3, and deep infection in 1 hip.

Discussion

In general this thesis showed that hip revision with impacted morselized allograft bone and cement performed as described by the inventors in Exeter and in Nijmegen is a well functioning hip revision technique. The patient outcome was good and comparable to that in primary hip replacement. No rigid initial fixation of the stems or the sockets was achieved but gradual stabilization occurred in the majority of the prosthetic components and no relationship was found between early and late movements of the stem or the socket. The stem subsided within the cement mantle and the stem-cement beam relative to the femur. There was however no apparent correlation between stem migration or socket migration or rotation and the degree of bone stock deficiency. With the intention to minimize prosthetic movements and the possibly associated inherent risk for future loosening, restricted weight bearing for several months after hip revision with impacted morselized allograft bone and cement has been the norm since this surgical procedure was introduced more than a decade ago. This postoperative regimen might still be appropriate in hips with pronounced bone stock deficiency. However, up to intermediate bone stock deficiency free weight bearing was not found to be detrimental for the prosthetic fixation. Free weight bearing would simplify the postoperative course for the patients.

Thus, the results concerning patient outcome and prosthetic fixation up to 5 years after hip revision with impacted morselized allograft bone and cement appear to be promising. This surgical procedure is, however, still technically demanding with an obvious risk for complications during surgery and the first 6 months after surgery. By being aware of the risks, monitoring the patients closely, and having experience in managing the various complications, even serious complications like complete femoral diaphyseal fractures can be treated without lasting morbidity.

Patient outcome

In the evaluation of hip replacement pain, physical function and quality of life should be regarded as the principal outcomes. These outcomes can now be adequately assessed by patient-answered questionnaires in a more valid and reliable manner than before when only outcomes recorded by the examining surgeon were available. At the time when hip revision with impacted morselized allograft bone and cement was introduced at our department in January 1994 we had experience in the use of the patient-administered Nottingham Health Profile (NHP) generic questionnaire in studies of primary hip replacement (Nilsson et al. 1994, Franzén et al. 1997). This made the NHP questionnaire a natural choice for us to administer to all patients planned for this new hip revision technique. At that time no validated hip-specific outcome instrument with higher sensitivity in detecting change in hip-related outcome was available.

The results of the NHP questionnaire showed substantial improvement in most health dimensions after hip revision with impacted morselized allograft bone and cement (Figure 1). The improvements were experienced after 6 months with no further improvement or deterioration up to 4 years after revision. Compared to before revision the largest improvement at 4 years occurred for pain and physical mobility but also energy and sleep improved. The scores for all health dimensions were similar to the 4-year NHP scores after primary cemented hip replacement performed at our department during the same time period and to those for patients in a randomly selected sample from the Swedish National Hip Arthroplasty Register (Söderman et al. 2000). This contradicts the prior opinion that hip revisions yield less favorable results than primary hip replacements. Both patients with hip revisions with impacted morselized allograft bone and cement, and patients with primary hip replacements experienced, however, more pain, lower physical mobility and less

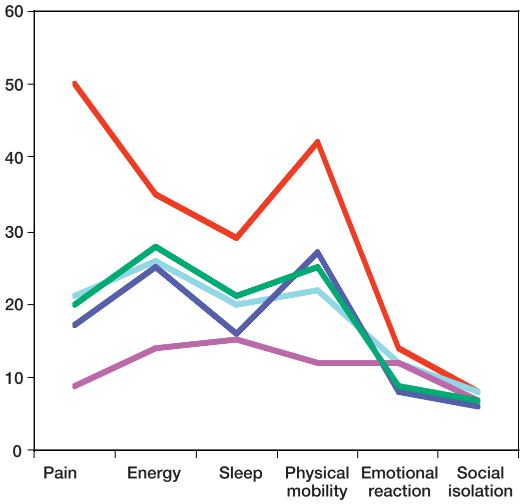


Figure 1. Scores for the Nottingham Health Profile (NHP) scales ranging from 0 (best) to 100 (worst health). Red graph represents scores before first-time revision for patients studied in this thesis who had aseptic loosening of a primary hip replacement performed because of osteoarthrosis; blue graph represents scores for the same patients 4 years after first-time revision with impacted morselized allograft bone and cement; green graph represents scores for osteoarthrotic patients during 4th year after primary hip replacement performed at our department during the same time period; turquoise graph represents scores 4 years after primary hip replacement for a patient sample randomly selected from the Swedish National Hip Arthroplasty Register (Söderman et al. 2000); violet graph represents scores for a randomly selected population sample from the catchment area of Lund University Hospital (Nilsson LT, personal communication 2002).

energy at 4 years than a randomly selected population sample from the catchment area of Lund University Hospital (216 women and 219 men aged 50 to 90 years), but the scores for sleep, emotional reactions and social isolation were similar (Nilsson LT, personal communication 2002).

The correlations between NHP outcomes based on the patient's self-report and the Charnley scores recorded by the examining surgeon were weak to moderate. This finding questions the use of only Charnley scores (or similar scoring systems) for the assessment of hip replacement and it is in line with previous findings of discrepancy between self-administered and examiner-administered outcomes (McHorney CA et al. 1994, Hoher et al. 1997, Lyons et al. 1999).

Prosthetic fixation

A major aim in hip replacement surgery is to optimize the prosthetic fixation according to known scientific rationales for sound prosthetic anchorage under prevailing conditions. In hip revision the biomechanical and biological basis for effective prosthetic fixation is more diversified than in primary hip replacement and thereby maybe less favorable. In hip revision with impacted morselized allograft bone and cement the idea is to create a balance between the favorable biological properties of morselized allograft bone and the impaction necessary to ensure primary stability. The allograft bone is supposed to be replaced by new bone which has been documented to occur at least partially (Ling et al. 1993, Nelissen et al. 1995, Ullmark and Linder 1998, Linder 2000, Ullmark and Obrant 2002b). The bone regeneration process includes revascularization, fibrous tissue ingrowth into the allograft bone, and graft resorption (Linder 2000, Tägil 2000). Lack of bone regeneration in favor of graft resorption could contribute to prosthetic migration and rotation. In this situation a collarless femoral stem might be beneficial by gradually allowing a smooth and non-constrained positional adaptation of the stem-cement beam.

At least 7 prerequisites for stem migration prevail in revision with impacted morselized allograft bone and cement (Figure 2). According to an experimental study on hip revision with impacted morselized allograft bone and a cemented collarless, double tapered and polished stem 50% of the distal migration of the stem during the first 5000 loading cycles occurred during the first 5 loading cycles (Malkani et al. 1996). This experimental phenomenon called settling might correspond to the clinical situation when the spontaneous hip muscle activity gradually resumes at the end of the anesthesia. It would be utmost difficult to document this very initial settling of the stem. But the ensuing stem movements can be visualized by early kinematic documentation with radiostereometric analysis (RSA) initiated before mobilization of the patient. As shown in this thesis considerable movements of both the stem and the socket in revisions with impacted morselized allograft bone and cement occur during the first week after surgery, which emphasizes the importance to perform the

Figure 2. Prerequisites for migration of a collarless, double tapered and polished stem in femoral hip revision with impacted morselized allograft bone and cement.
[1]Malkani et al. 1996, Kärrholm et al. 1999, Lee 2000; [2]Gie et al. 1993a, Nilsson and Kärrholm 1996, Eldridge et al. 1997, Kuiper et al. 1998, Brewster et al. 1999, Mikhail et al. 1999, Ullmark and Nilsson 1999; [3]Lee et al. 1978, Alfaro-Adrian et al. 1999, Stefánsdóttir et al. 1999, Ornstein et al. 1999a, Lee 2000; [4]Dohmae et al. 1988, Taylor and Tanner 1997; [5]Ullmark and Nilsson 1999, Linder 2000, Tägil 2000; [6]Ling 1992, Verdonschot and Huiskes 1996, Lee 2000; [7]Poss et al. 1987, Hofmann et al. 1989, Robinson et al. 1994.

RSA index examination as early as possible. By standardization of the timing of this early RSA index examination a sound base could be created for fruitful comparative research at different orthopaedic departments with RSA facilities. This could be helpful in the continuous quest to determine the effects of different prosthetic concepts, like collarless or collar-supplied stems, tapered or rounded stems and polished or matte stems, in hip revision with allograft bone. It could also be helpful in the work aimed at improving prosthetic fixation by optimized allograft bone composition, handling and impaction and reduced cold flow/creep and fatigue in the cement.

In the 15 collarless, double tapered and polished Exeter stems used in revisions with impacted morselized allograft bone and cement and followed with RSA for 5 years the most pronounced migrations occurred within the first 6 weeks after revision and all stems migrated in the distal direction. As previously suggested (Gie et al. 1993a, Malkani et al. 1996) this initial distal stem migration was shown to occur both within the cement mantle and for the stem-cement beam relative to the femur. The migration of the stem could be explained by the absence of a stem collar, the polished stem surface and/or cold flow/creep in the cement. The migration of the stem-cement beam could be explained by subsidence in the allograft bone because of the absence of a stem collar, compression and slippage of the allograft and/or decreased shear strength in the absence of cancellous bone (Figure 2). 11 stems continued to migrate to a minor degree in at least 1 direction in a leveling-out fashion between 2 and 5 years. This might be a sign of gradual positional adaptation of the stem-cement beam in the ongoing balanced process between stabilizing bone regeneration and destabilizing graft resorption, cement fatigue and physiological femoral enlargement. No apparent sign of radiographic loosening or clinical deterioration was noticed at 5 years but a minor femoral enlargement was observed. Another stem showed a continuous major distal migration to more than 5 mm at 5 years with concomitant wobbling in the medial-lateral and anterior-posterior directions. Even in this case there were no obvious signs of radiographic loosening and the patient was pain free at 5 years. This stem loosening according to RSA could not have been anticipated by the degree of preoperative bone stock deficiency, the quality of bone packing and cement filling, stem positioning or early migration pattern as none of these entities predicted late stem migrations. In prior RSA reports on stem revisions with impacted morselized allograft bone and cement followed between 1 and 3 years similar initial migrations have been shown in a study of heterogeneous stems and allograft bone techniques (Franzén et al. 1995), and less initial migrations in a study of collar-supplied, rounded and matte stems (Kärrholm et al. 1999). These migrations, however, might have been more pronounced than reported because the authors performed their RSA index examinations between 5 and 10 days after surgery while our examinations were performed at a median of 2 days. This exemplifies well how lack of standardization of the timing of the RSA index examination renders interpretation difficult, as in this case of the effects of proximal stem collar, stem geometry and stem surface character. In RSA studies on conventionally cemented hip revisions followed 1 to 2 years there are examples of both comparable stem migration (Franzén et al. 1992) and of less stem migration (Snorrason and Kärrholm 1990). To our knowledge no published RSA study has presented any 5-year results for conventionally cemented revisions or revisions with impacted morselized allograft bone.

Most prerequisites for stem migration in revisions with impacted morselized allograft bone and cement except femoral physiological expansion should also have some explanatory value for socket movements. The cancellous character of the acetabulum and the different biomechanical situation of the socket should however yield same alterations of the prerequisites.

In the 17 Exeter sockets used in revisions with impacted morselized allograft bone and cement and followed with RSA for 5 years the most pronounced socket migrations and rotations occurred within the first 6 weeks after revision, and almost all sockets migrated in the proximal direction. 5 sockets showed signs of radiographic loosening and allograft resorption at 5 years (Figure 3). These sockets had 2 to 3 times larger migration and 3 to 5 times larger rotation compared to those without signs of radiographic loosening but the patients experienced good pain relief. This could not have been anticipated by the degree of preoperative bone stock deficiency or the RSA follow-up as no specific bone stock deficiency or early migration/rotation pattern predicted late socket movements. The future will reveal whether the presumably ongoing new bone formation will dominate and stabilize the sockets, or the allograft resorption will prevail with clinical loosening as a result and a long-term rerevision rate similar to that of the inventors in Nijmegen found 10 to 15 years after revisions (Schreurs et al. 1998). If

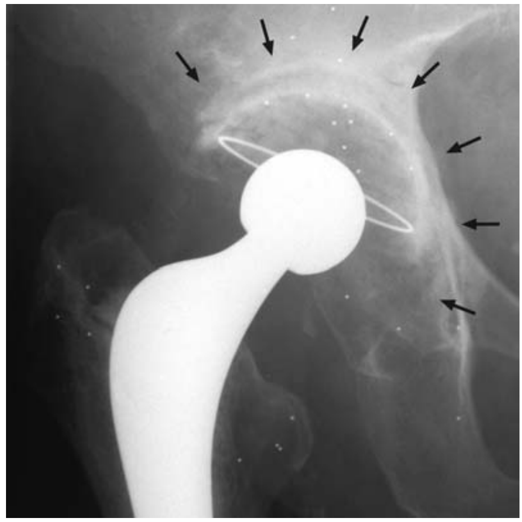


Figure 3. Socket 5 years after revision with impacted morselized allograft bone and cement with a radiolucent line >2mm in all 3 zones according to DeLee and Charnley (1976). Radiography also revealed allograft resorption and RSA major socket migration and rotation, but as the patient had no pain in the hip and the bone stock was not threatened rerevision was not considered.

new sockets will have the same fate, the longevity of socket revision with impacted morselized allograft bone and cement will be in question. However, the remaining 12 sockets had ceased to migrate and rotate and showed no signs of apparent radiographic loosening or allograft resorption at 5 years, and the patients experienced good pain relief. The rate of radiographic loosening was not worse in a mid-term perspective than that reported by other authors with radiographic loosening in 44 to 71% in series of conventionally cemented socket revisions (Kavanagh et al. 1985, Engelbrecht et al. 1990, Strömberg 1995) and in 17 to 69% in series of cementless socket revisions (Silverton et al. 1995, Chareancholvanich et al. 1999). The initial socket migrations as measured by RSA were more pronounced than in conventionally cemented socket revisions followed 1 to 2 years, but the decrease over time was similar (Snorrason and Kärrholm 1990, Franzén et al. 1993). This discrepancy might be explained by different timing of the RSA index examination, which we performed at a median of 2 days after surgery and the other authors performed between 1 and 3 weeks. This exemplifies once more the importance of standardized timing of the RSA index examination to facilitate correct comparisons, as in this case between cemented sockets with or without impacted morselized allograft bone.

Although the allograft bone appearance on radiographs implied some bone regeneration both in femur and in acetabulum, the question still remains whether these radiographic findings are significant. In both femur (Linder 2000) and acetabulum the radiographic appearance of the allograft bone has been difficult to relate to the promising histiological results of impaction grafting in animals and man (Roffman et al. 1983, Schreurs et al. 1994, Buma et al. 1996, Schreurs et al. 1998, Lamerigts et al. 2000),

The initial analysis of the clinical and radiostereometric results in hip revision with impacted morselized allograft bone and cement was performed after 2 years in 18 Exeter stems and 21 Exeter sockets. The patients fared well and the migrations of both the stems and the sockets decreased gradually in a promising way. In accordance with the principles outlined by the inventors of this surgical technique the patients had been instructed to restrict weight bearing on their operated hip with the use of crutches during 3 months after surgery (Slooff et al. 1993, Gie et al. 1993a). This was done with the intention to minimize prosthetic movements and the possibly associated inherent risk of future loosening. Because the initial results were promising we decided to implement the scientific basis of the benefits of weight bearing for the skeletal healing process and to alleviate the initial postoperative months for the patients with no large preoperative bone stock deficiency or major surgical complications, by allowing free weight bearing. This was done as part of a continuous scientific quest for improved hip revision results. Because this was a new postoperative regimen, careful patient monitoring was mandatory to discover any early signs of inferior surgical results that would justify return to the principles of restricted weight bearing; however, no discouraging results occurred except for 1 stem with radiostereometric and radiographic loosening. In the remaining 6 stems and all sockets for which free weight bearing was allowed, RSA at 2 years after revision revealed similar migration patterns as observed in the earlier operated patients for whom initial restricted weight bearing was demanded. These short-term results of free weight bearing appear promising but caution is advised in the interpretation of the findings because the number of patients was small and mid-term follow-up is still lacking. Our present practise is to allow free weight bearing for patients with up to intermediate bone stock deficiency and with no specific surgical complication that would require restriction of weight bearing.

Risks

Although initial reports on hip revisions with impacted morselized allograft bone and cement showed good clinical results when this revision technique was introduced at our department in January 1994 we were well aware of the risk for and had experience of complications in conventional hip revision surgery. We had also noticed an unfortunate lack of completeness in reports on these complications (Table). This rendered us some problems in the interpretation of the risks presented and whether to expect complications to occur during or after surgery. These were the rationales for our decision to prospectively register and analyze all complications and technical incidents that occurred during and within the 1st year after all hip revisions with impacted morselized allograft bone and cement.

Complications or technical incidents were recorded in 63 of the 139 patients with 144 hip revisions with impacted morselized allograft bone and cement. The rate of thromboembolic complications was similar to other reports (Eisler et al. 2000, Katz et al. 2001) with lasting morbidity in only 1 patient. The rate of hip complications was high, mainly in association with femoral revision, with the most serious being femoral fracture. There were 13 proximal (isolated fractures of greater trochanter not included) and 18 diaphyseal femoral fractures (Figure 4). 21 fractures (15% of all revisions) occurred during surgery, but 10 (7%) occurred later within 5 months after revision and all except 2 originated from a diaphyseal cortical window or perforation. Concomitant diseases (Charnley category C) and larger bone stock deficiency (type II and III) also increased the risk for femoral fractures. These risk factors emphasize the importance of meticulous surgical technique especially in patients with more advanced bone stock deficiency and concomitant diseases. All surgical hip complications could be handled without lasting morbidity.

The reported rates of femoral fracture during surgery vary from 7 to 24% in hip revisions with impacted morselized allograft bone and cement (Meding et al. 1997, Leopold et al. 1999, Ullmark et al. 2002a), from 5 to 19% in conventional revisions with cement (Retpen et al. 1989, Kershaw et al. 1991, Hultmark et al. 2000) and from 7 to 20% in uncemented revisions (Lord et al. 1988, Morrey and Kavanagh 1992, Egan and Di Cesare 1995). Unfortunately, most reports did not distinguish between proximal and diaphyseal fractures and did not precisely define risk factors, which limits a comparison of severity. Proximal fractures are usually detected during surgery and do not seem to be associated with additional complications. In other studies the rates of postoperative diaphyseal femoral fractures varied from 4 to 10% after hip revisions with impacted morselized allograft bone and cement (Elting et al. 1995, Williams and Maheson 1997, van Biezen et al. 2000, Ullmark et al. 2002) and from 4 to 6% after conventional revisions with cement (Amstutz et al. 1982, Kavanagh et al. 1985).

Femoral fracture frequently arises from both cortical window and femoral perforation (Callaghan et al. 1985, Kavanagh et al. 1985). Femoral cortical window, recorded in 7 hips (5%), has previously been reported to have been performed in 9% (Kershaw et al. 1991) to 60% (Wirta et al. 1993) of cemented revisions. Incidental femoral perforation, recorded in 14 hips (10%), has previously been reported to occur in 6% (Meding et al. 1997) to 16% (Knight and Helming 2000) of hip revisions with impacted morselized allograft bone and cement, in 9% (Hultmark et al. 2000) to 15% (Amstutz et al. 1982) of conventional revisions with cement, and in 17% of uncemented revisions (Egan and Di Cesare 1995). Long stems bypassing the window or perforation with a distance of twice the femoral diameter has been suggested to prevent fracture (Kavanagh et al. 1985), which is supported in this thesis. Long stems can also be beneficial for bypassing osteolytic areas and other cortical defects as an alternative or a complement to cerclage wiring or plating in the endeavor to prevent the development of complete femoral fractures. For proximal cracks cerclage wiring seems sufficient. In cases with severe femoral bone stock deficiency, especially in combination with comminuted femoral fractures stems with distal femoral anchorage might be considered (Wagner 1987, Kolstad 1994, Isacsson et al. 2000).

By proper attention to and surgical management of cortical windows and perforations as well as other complications and technical incidents during and after hip revision with impacted morselized allograft bone and cement good end result without lasting morbidity can be obtained (Figure 4).

Table. Reported complications in hip revision studies. Number of hips (A), femoral cortical deliberate windows or incidental perforations (B), femoral fractures during surgery (C) and femoral fractures after surgery (D)

	A	B	C	D
Revisions with impacted morselized allograft bone and cement				
Gie et al. 1993	68	?	2	1
Weidenhielm et al. 1994	89	?	?	0
Franzén et al. 1995	5	2+?	1	0
Elting et al. 1995	56	?	?	3
Meding et al. 1997	34	2+?	4	2
Eldridge et al. 1997	79	?	?	?
Masterson et al. 1997	35	?	6	?
Williams & Maheson 1997	75	2	0	3
Mikhail et al. 1999	43	?	?	2
Kärrholm et al. 1999	24	?	0	1
Leopold et al. 1999	25	2+?	6	?
Van Biezen et al. 2000	21	?	?	2
Pekkarinen et al. 2000	68	?	13	5
Knight et al. 2000	31	5+?	6	?
De Roeck et al. 2001	30	?	?	1
Lind et al. 2002	87	?	20%	?
Piccaluga et al. 2002	59	?	11	?
Conventionally cemented revisions				
Amstutz et al. 1982	66	20+	1	4
Callaghan et al. 1985	166	19	0	3
Rubash et al. 1988	43	8	2	3
Retpen et al. 1989	170	?	33	?
Marti et al. 1990	60	?	2	?
Kershaw et al. 1991	276	40	13	1+?
Wirta et al. 1993	101	61	12	?
Katz et al. 1997	106	1	3	1
Hultmark et al. 2000	109	10	8	?
Eisler et al. 2000	83	?	?	?
Uncemented revisions				
Lord et al. 1988	284	?	14	3
Morrey et al. 1992	116	?	21	?
Lawrence et al. 1993	193	?	1	?
Önsten et al. 1995	45	?	6	?
Egan et al. 1995	135	23	27	?
Mulliken et al. 1996a	52	-	20	-
Krishnamurthy el al. 1997	297	?	?	13

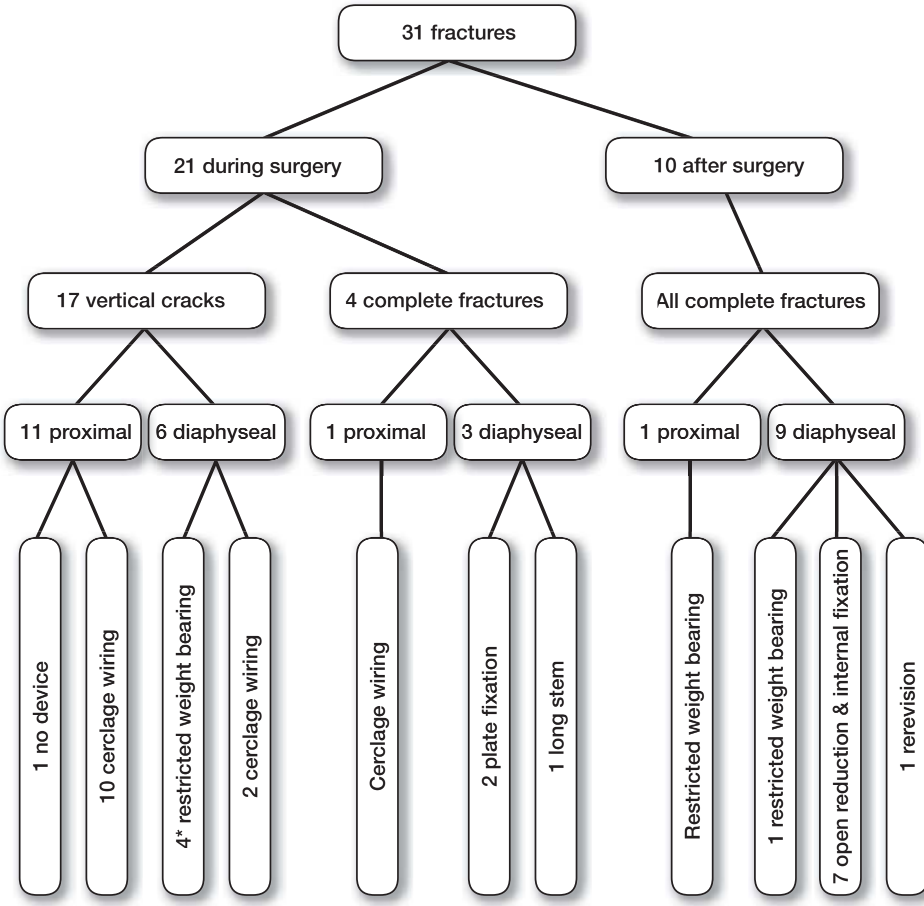


Figure 4. Flow diagram of fractures during and after surgery in 144 hip revisions with impacted morselized allograft bone and cement. All fractures could be handled without lasting morbidity.
* detected immediately after surgery.

In summary

This thesis contradicts the opinion that hip revisions with impacted morselized allograft bone and cement yield worse patient outcomes than primary hip replacements at least in a mid-term perspective. Prosthetic migration within reasonable limits is not necessarily equivalent to classical aseptic loosening with clinical deterioration, at least not with a collarless, double tapered and polished stem. Hip revision is a major surgical challenge, irrespective of the revision technique chosen, associated with many technical incidents and complications. By being aware of these risks, having the correct equipment available and having appropriate surgical experience, the various complications can be treated without lasting morbidity. Thus, the patients can benefit from the promising results for outcomes and prosthetic fixation in hip revisions with impacted morselized allograft bone and cement. More standardized logistics and follow-up content would make it easier to further improve the prosthetic concept and the surgical technique in hip revision surgery.

Conclusions

The findings of this thesis support the following conclusions for hip revisions with impacted morselized allograft bone and cement as described by the inventors in Exeter and Nijmegen:

- Improvements of pain, physical mobility, sleep and energy as measured by the NHP questionnaire can be obtained within 6 months after revision and maintained for 4 years.
- Revisions and primary replacements yield similar health status and quality of life outcomes after 4 years as measured by the NHP questionnaire.
- The correlations between the NHP scores for pain and physical mobility and the Charnley scores for pain and walking ability are weak to moderate. This supports validated patient-answered questionnaires as the main instrument to monitor patient outcome.
- Considerable distal stem migration and proximal socket migration occur during the 1st week after revision emphasizing the need of early RSA index examination.
- The collarless, double tapered and polished Exeter stem can subside within the cement mantle with concomitant subsidence of the stem-cement beam relative to the femur.
- All stems migrate (subside) in the distal direction.
- Stem migrations are more pronounced early after revision with a gradual decreasing migration rate in a leveling out fashion. Most stems continue to migrate marginally in at least 1 direction between 2 and 5 years after revision normally without any clinical deterioration.
- No early pattern of stem migration predicts future migration.
- The total stem migration at 5 years after revision cannot be correlated to bone stock deficiency, quality of bone packing, cement filling, stem positioning or radiolucent lines.
- Almost all sockets migrate in the proximal direction.
- Socket migrations and rotations are more pronounced early after revision with a gradual decreasing migration rate and rotation rate in a leveling out fashion. A minority of the sockets continue to migrate and/or rotate at 5 years after revision normally without any clinical deterioration.
- No early patterns of socket migration or socket rotation predict future migration or rotation.
- The total socket migration and rotation at 5 years after revision cannot be correlated to bone stock deficiency.
- Free weight bearing immediately after revision might not be detrimental for stem or socket fixation.
- Hip related complications and technical incidents are frequent but thromboembolic complications are infrequent.
- Concomitant disease, large bone stock deficiency and cortical diaphyseal window or perforation during revision increase the risk for femoral fracture.
- Hip related complications and technical incidents can be treated without lasting morbidity.

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Gradually I have become more and more aware of the importance of creating conditions for systematic patient follow-ups, i.e. clinical research, as an integrated part of our daily work. This is probably necessary for progress of evidence based medicine in health care practice. I think this can be recommended for future colleagues, leaders, officials as well as politicians, in the Swedish health care system.

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Appendix

Paper I

Quality-of-life outcomes in hip revision arthroplasty with impacted morselized allograft bone and cement: comparison with primary arthroplasty

The scores for the Nottingham Health Profile (NHP) scales

	Revision arthroplasty						Primary arthroplasty
	Preoperative	**Postoperative**					**Postoperative**
NHP scale [a]	(n 47)	**6 months** (n 43)	**1 year** (n 46)	**2 years** (n 41)	**3 years** [b] (n 43)	**4 years** [b] (n 36)	**3–4 years** [b] (n 144)
Pain	50 (29)	16 (26)	13 (18)	15 (19)	13 (18)	17 (22)	20 (26)
Physical mobility	42 (21)	26 (26)	24 (24)	27 (25)	26 (26)	27 (27)	25 (24)
Energy	35 (37)	24 (36)	19 (32)	21 (35)	23 (35)	25 (38)	28 (37)
Sleep	29 (28)	15 (23)	19 (29)	16 (21)	19 (24)	16 (20)	21 (27)
Emotional reaction	14 (20)	9 (18)	7 (12)	6 (13)	12 (20)	8 (13)	9 (19)
Social isolation	8 (13)	5 (17)	6 (12)	6 (13)	7 (15)	6 (12)	7 (17)

[a] The NHP scores shown as mean (SD); score ranges from 0 (best) to 100 (worst).
[b] No significant differences in the scores between the revision and primary arthroplasty groups in any scale.

The within-subject differences between the preoperative scores and the 3-year and 4-year postoperative scores for the Nottingham Health Profile (NHP) scales. The effect size (magnitude of health improvement) at four years after revision surgery noted

	Preoperative – 3 years			Preoperative – 4 years			
NHP scale [a]	n	mean	difference (95% CI)	n	mean	difference (95% CI)	effect size [b]
Pain	41	37	(27 to 47)***	34	33	(21 to 45)***	1.1
Physical mobility	41	13	(5 to 22)**	35	13	(3 to 23)*	0.7
Energy	40	10	(–1 to 21)	34	4	(–7 to 14)	0.1
Sleep	41	9	(2 to 15)*	34	7	(–1 to 15)	0.3
Emotional reaction	39	3	(–3 to 9)	32	5	(–2 to 11)	0.2
Social isolation	40	2	(–2 to 7)	33	–1	(–6 to 3)	–0.1

[a] The NHP score ranges from 0 (best) to 100 (worst).
[b] Mean difference in scores divided by the standard deviation for the preoperative scores (effect size of 0.2 indicates small, 0.5 moderate, and 0.8 or greater large health improvement).
*p < 0.05, **p <0.01, ***p < 0.001

Paper II

Radiostereometric analysis in hip revision surgery: optimal time for index examination

Data and RSA migration of 6 stems and 5 sockets revised with impacted morselized allograft bone and cement

				Femoral component																	
A	B	C	D	Distal migration (mm) Accuracy 0.3 mm						Medial migration (mm) Accuracy 0.5 mm						Posterior migration (mm) Accuracy 0.6 mm					
Days after surgery				7	14	21	28	35	42	7	14	21	28	35	42	7	14	21	28	35	42
1	m	l	II	0.7	0.9	1.2	1.4	1.5	1.5	-	-	-	-	-	-	0.9	1.4	1.8	2.0	2.1	2.3
2	f	l	II	2.1	2.6	2.9	3.4 [d]	3.5	3.7	0.7	0.7	0.8	0.8*	0.8	0.6	2.9	3.5	4.0	4.2 [d]	4.6	4.7
3 [a]	m	r	II	0.6	2.5	3.6	4.1	4.6	4.8	0.9	3.0	3.6	3.9	3.9	4.0	1.3	5.2	7.1	8.1	8.4	9.0
4 [a]	m	l	II	0.6	0.6	0.8	1.0	1.2	1.3	-	-	-	-	-	-	0.5	-	1.1	-	0.8	-
5 [b]	m	l	II	0.4	0.9	1.1	1.4	1.4	1.7	-	0.5	-	-	0.6	0.5	0.7	1.0	1.4	0.8	1.4	1.3
6	f	r	II	0.4	1.0	1.3	1.5	1.6	1.8	-	-	-	-	-	-	1.2	2.1	2.4	2.4	2.6	2.6
				Acetabular component																	
A	B	C	E	Proximal migration (mm) Accuracy 0.2 mm						Lateral migration (mm) Accuracy 0.3 mm						Posterior migration (mm) Accuracy 0.3 mm					
Days after surgery				7	14	21	28	35	42	7	14	21	28	35	42	7	14	21	28	35	42
1	m	l	c																		
2	f	l	II	0.2	0.3	0.3	0.4 [d]	0.3	0.4	-	-	-	- [d]	-	-	-	-	-	- [d]	-	-
3	m	r	II	0.5	0.8	1.2	1.4	1.6	1.8	-		0.4	0.4	0.4	0.5	-	-	-	-	-	-
4 [a]	m	l	II	-	-	-	-	-	-	-	-	-	-	0.3	0.4	-	-	-	-	-	-
5 [b]	m	l	II	0.2	0.4	0.5	0.6	0.7	0.5	-	-	-	-	-	-	-	-	-	-	-	0.3
6	f	r	II	-	0.2	0.3	0.4	0.4	0.5	-	-	-	-	-	-	-	-	-	-	-	-

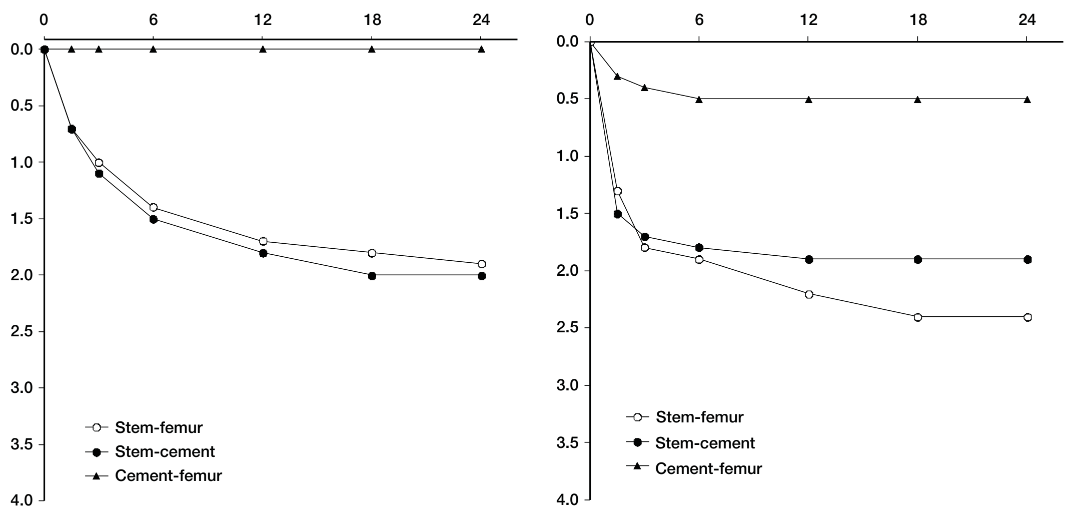
A Patient and hip number
B Gender
C Side
D Femoral bone stock deficiency according to Gustilo and Pasternak (1988)
E Acetabular bone stock deficiency according to Gustilo and Pasternak (1988)
- No migration
[a] Infected
[b] The patient that used 1 crutch between 4 and 6 weeks after surgery
[c] Not revised
[d] Examination on the 29th day

Paper III

Early subsidence of the Exeter femoral stem within the cement mantle in primary arthroplasties and in revisions using impacted allografts and cement: a roentgen stereophotogrammetric analysis

RSA distal migration (subsidence, mm) for 2 primary Exeter stems and 2 Exeter stems revised with the X-change instruments system (accuracy 0.2 mm)

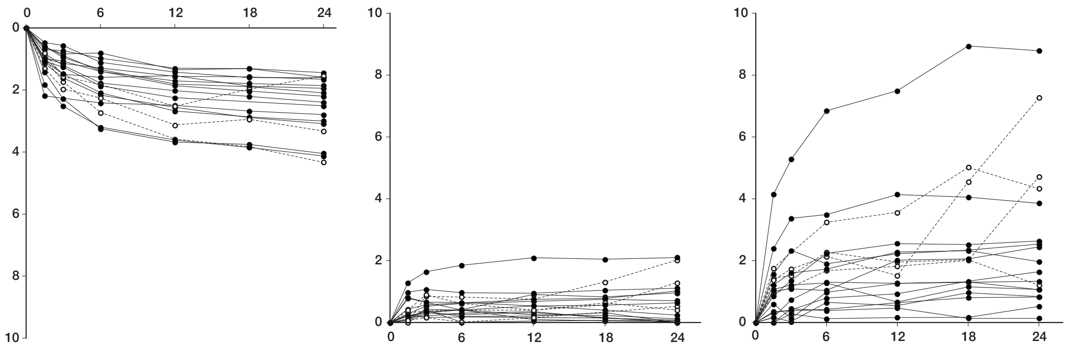
Months	1.5	3	6	12	18	24	1.5	3	6	12	18	24	1.5	3	6	12	18	24
	Stem relative to cement						Stem relative to femur						Cement relative to femur					
Primary 1	0.7	0.9	0.9	1.0	1.2	1.4	0.7	0.9	0.9	1.1	1.2	1.4	0	0	0	0	0	0
Primary 2	0.7	1.1	1.5	1.8	2.0	2.0	0.7	1.0	1.4	1.7	1.8	1.9	0	0	0	0	0	0
Revision 1	1.5	1.7	1.8	1.9	1.9	1.9	1.3	1.8	1.9	2.2	2.4	2.4	0.3	0.4	0.5	0.5	0.5	0.5
Revision 2	1.3	1.9	2.3	2.7	2.8	3.1	1.7	2.6	3.0	3.3	3.5	3.6	0	0.3	0.3	0.3	0.4	0.4



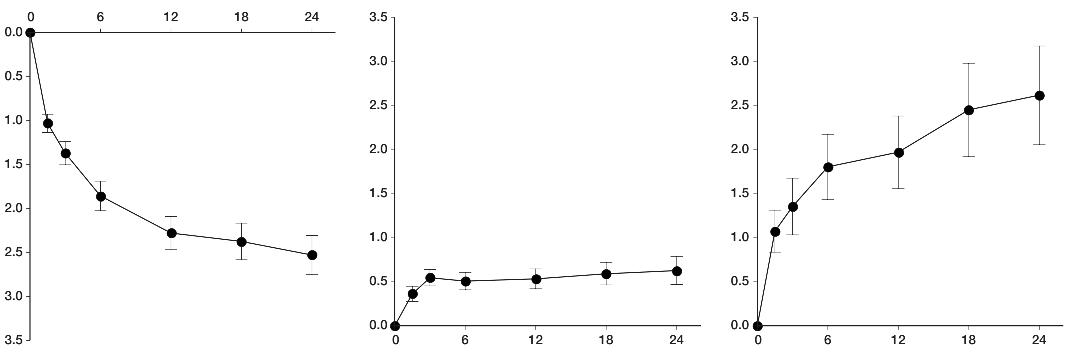
Migration (mm) during 24 months for the 2nd of the 2 primary hip replacements (left) and for the 2nd of the 2 revisions (right). Distal stem migration was observed within the cement mantle. In the revision, additional distal migration of the stem-cement beam in relation to the femur was observed.

Paper IV

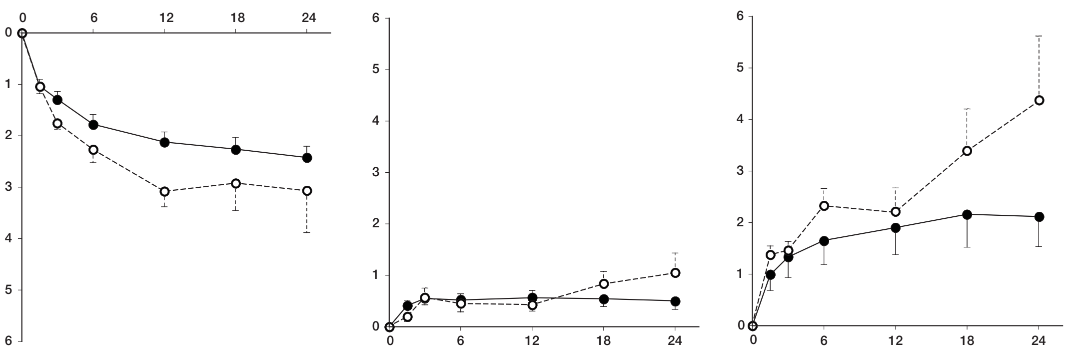
Results of hip revision using the Exeter stem, impacted allograft bone and cement (2-year follow-up)



Migration (mm) for each of 18 stems up to 24 months: distal migration (left), medial-lateral (middle), posterior (right). Dotted lines represent stems still migrating between 1.5 and 2-year follow-up.



Mean (SE) migration (mm) of all 18 stems up to 24 months: distal migration (left), medial-lateral (middle), posterior (right).



Mean (SE) migration (mm) of 18 stems up to 24 months: distal migration (left), medial-lateral (middle), posterior (right). Dotted line represents stems still migrating between 1.5 and 2-year follow-up.

Data and RSA migration (mm) of 18 stems revised with morselized allograft bone and cement, restricted weight bearing (accuracy: distal migration 0.3 mm, medial or lateral migration 0.5, and posterior migration 0.6 mm)

Months after revision				1.5	3	6	12	18	24	1.5	3	6	12	18	24		1.5	3	6	12	18	24				
A	B	C	D	Distal migration						Medial or Lateral migration							Posterior migration							E	F	G
1	m	R	I	0.6	0.8	0.8	1.3	1.3	1.4	0.3	0.5	0.6	0.7	0.8	0.7	M	0.4	0.4	0.4	0.6	0.8	0.8	P	No	No	No
2	m	R	I	0.7	0.7	1.0	1.3	1.3	1.6	0.0	0.3	0.3	0.3	0.2	0.0	-	0.0	0.4	0.4	0.5	0.1	0.1	-	No	No	No
3	f	L	I	1.0	1.7	2.7	3.6	3.8	4.3	0.3	0.4	0.4	0.4	0.6	1.3	M	0.9	1.1	1.7	1.8	2.0	4.7	P	0.5	0.7	2.7
4	f	R	II	2.2	[a]	2.4	2.5	2.7	2.8	0.8	[a]	0.4	0.1	0.1	0.0	-	1.8	[a]	3.2	3.6	5.0	4.3	P	No	No	0.7
5	m	L	III	1.0	1.5	1.6	1.5	1.9	1.9	0.2	0.2	0.2	0.2	0.1	0.0	-	1.4	1.5	2.3	2.0	2.0	1.2	P	No	No	0.8
6	f	R	I	0.6	1.0	1.3	1.8	1.9	2.1	0.1	0.4	0.0	0.0	0.1	0.1	-	0.2	0.0	0.7	0.5	1.0	0.8	P	No	No	No
7	m	R	III	0.8	1.2	1.8	2.0	2.2	2.4	0.2	0.2	0.3	0.4	0.1	0.1	-	0.2	0.7	1.3	1.3	1.3	1.1	P	No	No	No
8	f	L	II	0.5	0.6	1.1	1.4	1.6	1.6	0.2	0.3	0.4	0.5	0.4	0.2	-	0.3	0.4	0.8	0.9	1.3	1.6	P	No	No	No
9	f	R	II	1.1	1.6	2.2	2.6	2.9	3.1	0.2	0.3	0.4	0.9	0.8	1.0	M	1.0	1.1	1.0	2.0	2.1	2.4	P	No	No	No
10	m	R	II	0.8	1.6	1.8	2.5	2.0	1.5	0.0	0.8	0.8	0.8	1.3	2.0	M	1.4	1.7	2.1	1.5	4.6	7.3	P	0.5	0.7	2.7
11	m	R	II	1.0	1.1	1.4	1.7	1.8	1.9	1.0	1.1	1.0	0.9	1.0	1.1	M	1.6	2.3	1.9	2.2	2.3	2.5	P	No	No	No
12	m	R	II	1.1	1.5	2.1	2.7	2.9	3.0	0.1	0.4	0.4	0.3	0.2	0.1	-	0.9	1.4	2.2	2.6	2.5	2.6	P	No	No	No
13	m	L	II	1.0	1.1	1.3	1.6	1.6	1.7	0.1	0.4	0.2	0.2	0.3	0.0	-	0.0	0.3	0.1	0.2	0.2	0.5	-	No	No	No
14	f	R	III	0.6	0.9	1.4	1.9	2.0	2.2	0.4	0.6	0.6	0.7	0.8	1.0	L	1.2	1.6	1.7	2.3	2.3	2.0	P	No	No	No
15	f	R	II	1.1	1.3	1.9	2.2	[a]	2.5	0.1	0.2	0.0	0.2	[a]	0.5	L	0.6	0.1	1.0	1.3	[a]	1.3	P	No	0.5	No
16	m	R	II	1.3	2.0	2.3	3.1	2.9	3.3	0.4	0.9	0.6	0.4	0.6	0.4	L	1.1	1.2	1.3	0.7	1.2	1.1	P	0.4	0.6	No
17	m	L	I	1.4	2.3	3.2	3.7	3.8	4.0	0.8	0.7	0.6	0.5	0.6	0.6	M	4.1	5.3	6.8	7.5	8.9	8.8	P	No	No	No
18	m	R	I	1.8	2.5	3.2	3.6	3.9	4.1	1.3	1.6	1.9	2.1	2.0	2.1	M	2.4	3.4	3.5	4.1	4.1	3.9	P	No	No	No

A Patient number
B Gender
C Side
D Bone stock deficiency according to Gustilo and Pasternak (1988)
E Distal migration between 1.5 and 2 years (No or mm)
F Medial or lateral migration between 1.5 and 2 years (No or mm)
G Posterior migration between 1.5 and 2 years (No or mm)
[a] Missed RSA
\- Migration value less than accuracy

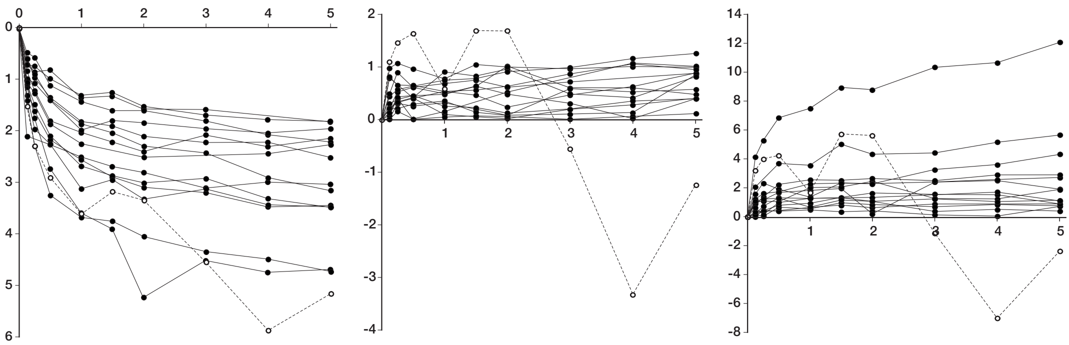
Preoperative and 2-year follow-up Charnley scores according to Charnley category (1979)

Category	Pain		Walking ability		Range of motion	
	Preoperative	Follow-up	Preoperative	Follow-up	Preoperative	Follow-up
A (n=3)	3 (3–4)	6 (6)	4 (2–5)	6 (4–6)	5 (4–5)	5 (4–5)
B (n=11)	3 (1–4)	6 (4–6)	3 (1–5)	4 (3–6)	5 (3–6)	5 (4–5)
C (n=4)	3 (1–5)	5 (4–6)	1.5 (1–4)	2 (1–4)	4.5 (2–6)	4.5 (4–5)

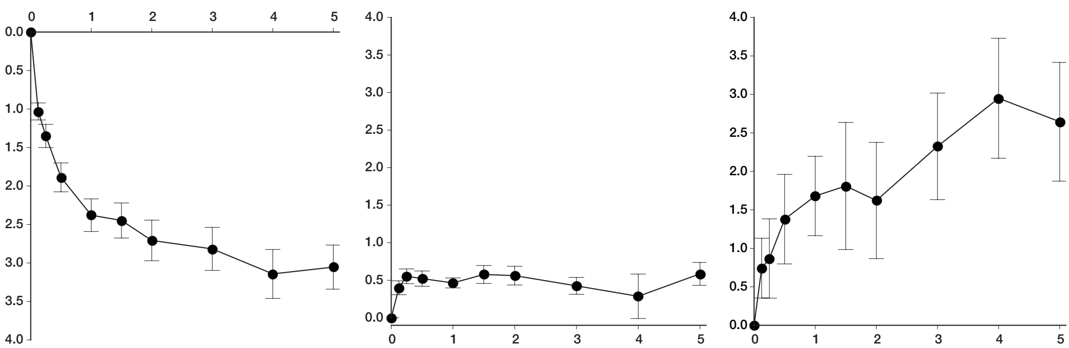
Data presented as median (range).

Paper V

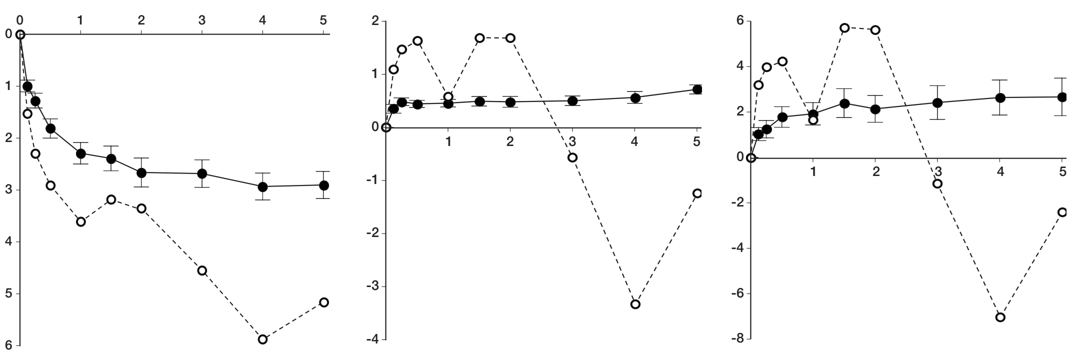
Hip revision arthroplasty using Exeter stem, impacted morselized allograft bone and cement. A prospective and consecutive five-year radiostereometric and radiographic study in 15 patients



Migration (mm) for each of 15 stems up to 5 years: distal migration (left), medial-lateral (middle), posterior (right). Dotted line represents the stem wobbling and judged to be loose according to RSA.



Mean (SE) migration (mm) of all 15 stems up to 5 years: distal migration (left), medial-lateral (middle), posterior (right).



Mean (SE) migration (mm) of 14 stems up to 5 years: distal migration (left), medial-lateral (middle), posterior (right). The 15th stem which was wobbling and judged to be loose according to RSA is presented separately.

RSA values for migration (mm) of 15 stems followed for 5 years

Years	0.13	0.25	0.5	1	1.5	2	3	4	5
Distal direction (accuracy 0.3 mm)									
1	0.7	0.8	0.8	1.3	1.3	1.6	1.6	[a]	1.8
2	0.7	0.7	1.0	1.3	1.2	1.5	1.7	1.8	1.8
3	1.0	1.7	2.7	3.6	3.9	5.2	4.5	4.7	4.7
4	2.1	[a]	2.3	2.5	2.7	2.8	3.1	3.0	3.0
5	0.6	1.0	1.3	1.8	1.9	2.1	2.2	2.2	2.5
6	0.8	1.2	1.8	2.0	2.2	2.4	2.1	2.3	2.1
7	0.5	0.6	1.1	1.4	1.6	1.6	1.8	2.1	2.2
8	1.1	1.6	2.2	2.6	2.9	3.1	3.2	3.5	3.4
9	1.0	1.1	1.4	2.0	1.8	1.8	2.0	2.0	2.0
10	1.1	1.5	2.1	2.7	2.9	3.0	2.9	3.3	3.5
11	0.6	0.9	1.4	1.9	2.0	2.3	2.4	2.9	3.2
12	1.1	1.3	1.9	2.2	[a]	2.5	[a]	2.4	2.3
13	1.3	2.0	2.3	3.1	2.9	3.3	3.1	3.4	3.5
14	1.4	2.3	3.2	3.7	3.8	4.1	4.3	4.5	4.7
15 [b]	1.5	2.3	2.9	3.6	3.2	3.3	4.6	5.9	5.2
Medial/lateral direction (accuracy 0.5 mm)									
1	0.2	0.5	0.6	0.7	0.8	0.6	0.7	[a]	0.9
2	0	0.3	0.3	0.3	0.2	0.1	0.1	0.1	0.9
3	0.3	0.4	0.5	0.5	0.6	1.0	0.6	0.6	0.5
4	0.8	[a]	0.4	0.1	0.1	0	0.2	0.3	0.4
5	0.1	0.4	0	0	0.1	0.1	0	0.1	0.1
6	0.2	0.2	0.3	0.4	0.1	0.1	0.6	0.5	0.6
7	0.2	0.3	0.4	0.5	0.5	0.2	0.5	0.6	0.9
8	0.2	0.3	0.4	0.9	0.8	1.0	0.5	0.4	0.8
9	1.0	1.1	1.0	0.8	1.0	1.0	1.0	1.0	1.0
10	0.1	0.4	0.5	0.3	0.2	0.1	0.2	0.4	0.4
11	0.4	0.6	0.6	0.7	0.8	0.9	1.0	1.2	1.3
12	0	0.2	0	0.2	[a]	0.5	[a]	1.1	1.0
13	0.5	0.9	0.6	0.5	0.6	0.5	0.3	0	0.4
14	0.8	0.7	0.6	0.5	0.6	0.6	0.9	1.1	1.0
15 [b]	1.1	1.5	1.6	0.6	1.7	1.7	-0.6	-3.3	-1.2
Posterior direction (accuracy 0.7 mm)									
1	0.2	0.4	0.4	0.6	0.8	0.6	0.9	[a]	0.9
2	0	0.4	0.4	0.5	0.3	0.4	0.1	0	0.7
3	0.9	1.1	1.7	1.8	1.9	0.2	2.4	2.5	1.9
4	2.1	[a]	3.7	3.6	5.0	4.3	4.4	5.2	5.7
5	0.2	0	0.7	0.6	1.0	0.8	0.7	0.8	0.8
6	0.2	0.7	1.3	1.3	1.3	1.1	0.4	0.5	0.4
7	0.3	0.4	0.8	0.9	1.3	1.6	1.5	1.5	0.9
8	1.0	1.1	1.0	2.0	2.1	2.4	1.3	1.2	1.9
9	1.6	2.3	1.9	1.4	2.3	2.3	2.4	2.6	2.7
10	0.9	1.4	2.2	2.6	2.5	2.6	2.5	2.9	2.9
11	1.2	1.6	1.7	2.3	2.3	2.3	3.3	3.6	4.3
12	0.6	0.1	1.0	1.3	[a]	1.3	[a]	1.7	1.1
13	1.1	1.2	1.3	0.7	1.2	1.1	1.2	1.0	1.1
14	4.1	5.3	6.8	7.5	8.9	8.8	10.3	10.7	12.1
15 [b]	3.2	4.0	4.2	1.7	5.7	5.6	-1.1	-7.0	-2.4

[a] missed RSA.
[b] Case number 15 wobbled back and forth and was judged to be loose according to RSA.

Data at surgery and at 5 years after 15 Exeter stem revisions with impacted morselized allograft bone and cement

Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gender	M	M	F	F	F	M	F	F	M	M	F	F	M	M	M
Side	R	R	L	R	R	R	L	R	R	R	R	R	R	L	R
Age	60	62	67	69	70	72	76	76	77	78	79	80	81	81	82
Weight (kg)	78	85	71	70	56	95	78	74	94	45	71	71	94	96	75
Patient category [a]	C	B	A	C	B	B	B	C	B	B	B	B	A	B	B
Bone stock deficiency [b]	I	I	I	II	I	III	II	II	II	II	III	II	II	I	I
Graft packing predominant [c,d]	G	F	D	G	G	F	G	F	G	G	F	F	F	F	G
Cement mantle defect [c]	Yes	Yes	Yes	-	Yes	-	Yes	Yes	-	Yes	Yes	Yes	-	Yes	-
Cement beyond tip of stem [c]	-	-	Yes	Yes	Yes	-	-	Yes	Yes	-	-	Yes	Yes	-	Yes
Stem position after surgery: degrees (-) varus, (N) neutral [e]	N	N	N	N	N	-6	N	N	N	N	N	N	N	-5	-4
Stem postion at 5 years: degrees (-) varus, (N) neutral	N	N	-4	N	N	-6	N	N	N	N	N	N	N	-4	-4
Pain [a]	3	1	4	3	4	1	4	6	4	3	3	2	3	2	3
Pain at 5 years	6	6	6	6	6	5	4	6	5	6	6	6	5	5	6
Walking ability [a]	2	3	4	1	4	4	3	4	1	5	2	1	2	3	5
Walking ability at 5 years	2	4	6	2	4	3	4	4	4	2	6	2	4	6	2
Range of motion (ROM) [a]	6	6	5	5	5	3	5	5	4	3	5	4	4	5	4
ROM at 5 years	5	5	5	4	4	3	4	5	5	3	5	4	4	6	5
Trabecular incorporation predominant at 5 years [g]	Yes	Yes	-	Yes	Yes	-	Yes	Yes	-	-	-	-	Yes	Yes	-
Trabecular remodeling predominant at 5 years [g]	-	-	-	-	-	-	-	-	Yes	-	-	-	-	-	-

[a] According to Charnley (1979)
[b] According to Gustilo and Pasternak (1988)
[c] According to Gie et al. (1993)
[d] E=Execellent, G=Good, F=Fair, P=Poor, D=Defective
[e] According to Eldridge at al. 1997
[f] Migrations (mm) by RSA according to Selvik (1989)
[g] According to Gie et al. (1993) and Linder (2000)

Quality of graft packing (Gie et al. 1993a). Predominant appearance in 15 hips and in 105 zones (Gruen et al. 1988)

Grade	Graft packing in 15 hips	Graft packing in 105 zones
Excellent	0	9
Good	7	45
Fair	7	25
Poor	0	12
Defective	1	14

Predominant allograft appearance (Linder 2000) 5 years after revision in 15 hips and in 105 zones (Gruen et al. 1988)

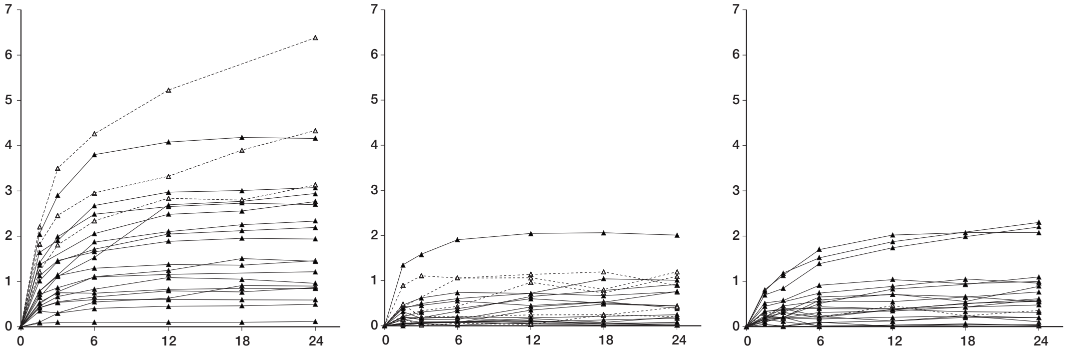
	Allograft appearance in 15 hips	Allograft appearance in 105 zones
No change	1	35
Cortical healing	0	11
Localized resorption	0	4
Trabecular incorporation	8	57
Trabecular remodeling	1	22
Not classified	0	0

Femoral bone width and endosteal diameter (cm) postoperatively and 5 years after revision (Karlsson et al. 1996)

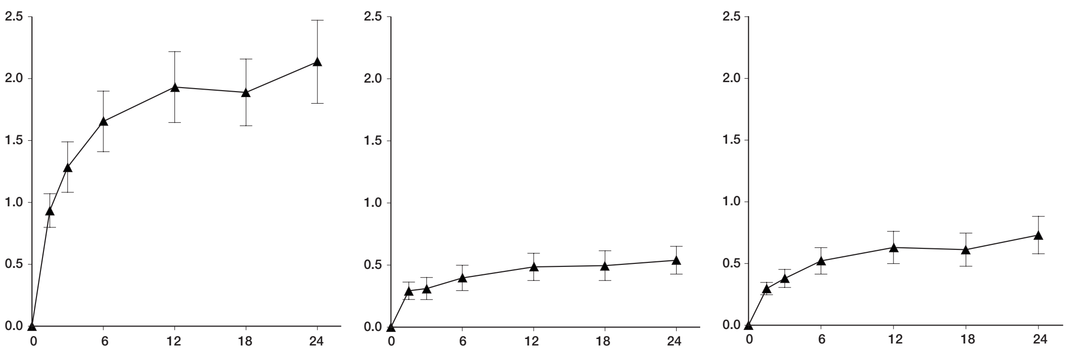
	Postoperatively	5 years	p-value
Periosteal below lesser trochanter	3.99 ±0.56	4.15 ±0.49	0.2
Periosteal below the tip of the stem	3.61 ±0.53	3.66 ±0.47	0.13
Endosteal below the tip of the stem	1.94 ±0.39	1.91 ±0.40	0.58

Paper VI

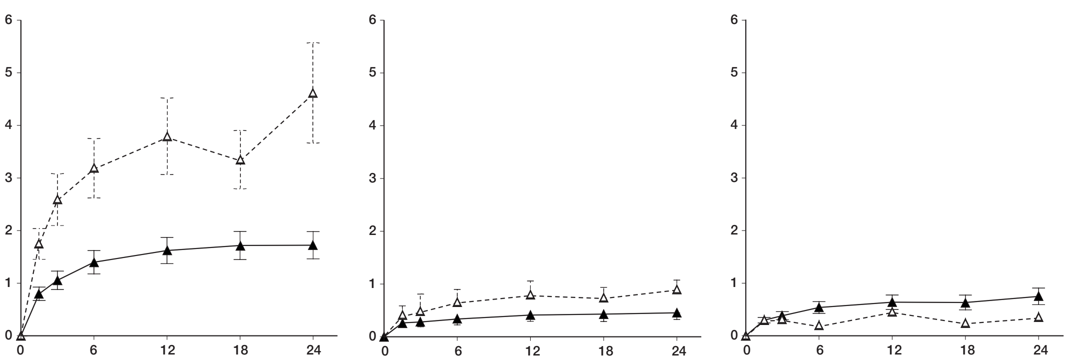
Migration of the acetabular component after revision with impacted morselized allografts. A radiostereometric 2-year follow-up analysis of 21 cases



Migration (mm) for each of 21 sockets up to 24 months: proximal migration (left), medial-lateral (middle), posterior-anterior (right). Dotted lines represent sockets still migrating between 1.5 and 2 years after revision.



Mean (SE) migration (mm) of all 21 sockets up to 24 months: proximal migration (left), medial-lateral (middle), posterior-anterior (right).



Mean (SE) migration (mm) of 21 sockets up to 24 months: proximal migration (left), medial-lateral (middle), posterior-anterior (right). Dotted lines represent sockets still migrating between 1.5 and 2 years after revision.

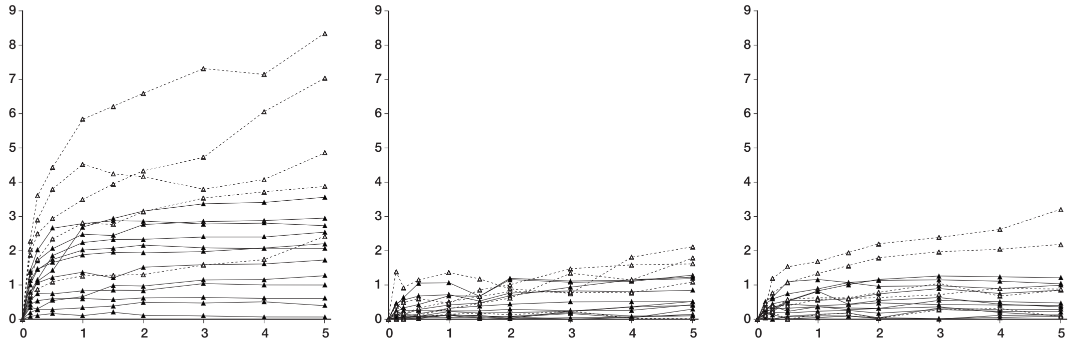
Data and RSA migration of 21 sockets revised with morselized allograft bone and cement, restricted weight bearing postoperatively (accuracy: proximal migration 0.2 mm, medial or lateral 0.3 mm and posterior or anterior 0.3 mm)

A	B	C	D	Proximal migration (mm)						Medial or lateral migration (mm)							Posterior or anterior migration (mm)							F	G	H
				1.5	3	6	12	18	24	1.5	3	6	12	18	24		1.5	3	6	12	18	24	months after revision			
1	M	r	III	0.8	1.1	1.3	1.4	1.4	1.5	0.5	0.6	0.7	0.7	0.7	0.8	M	0.2	0.5	0.6	0.6	0.7	0.8	P	No	No	No
2	F	l	III	0.3	0.3	0.5	0.6	0.9	0.9	0.2	0.3	0.4	1.0	0.7	1.1	M	0	0	0.1	0.1	0.2	0.1	-	No	0.4	No
3	F	r	III	1.4	a	2.1	2.5	2.6	2.8	0.4	a	1.1	1.1	0.8	1.2	M	0.4	a	0.7	0.9	1.1	1.0	P	No	0.4	No
4	M	l	III	0.5	0.8	1.1	1.2	1.5	1.4	0.4	0.5	0.6	0.4	0.5	0.4	L	0.2	0.3	0.2	0.4	0.5	0.6	P	No	No	No
5	F	r	III	1.4	2.0	2.5	2.7	2.7	2.7	0.1	0	0	0.1	0.1	0.2	-	0.5	0.6	0.9	1.0	0.9	1.0	P	No	No	No
6	M	l	II	0.6	1.1	1.5	2.7	2.8	2.9	0.2	0.1	0.1	0.4	0.5	0.8	L	0.2	0.2	0.5	0.8	0.9	1.1	P	No	No	No
7	M	l	III	1.6	1.9	2.7	3.0	3.0	3.1	1.4	1.6	1.9	2.0	2.1	2.0	L	0.8	1.1	1.7	2.0	2.1	2.1	P	No	No	No
8	F	r	III	1.8	2.5	3.0	3.3	3.9	4.3	0.9	1.1	1.1	1.1	1.2	0.9	M	0.7	0.8	1.4	1.7	2.0	2.2	P	0.4	0.3	No
9	F	l	II	1.0	1.4	1.7	2.0	2.1	2.2	0.1	0.1	0.1	0.1	0.1	0	-	0.3	0.3	0.2	0.5	0.2	0.4	P	No	No	0.4
10	F	l	II	1.1	1.5	1.7	1.9	2.0	1.9	0.5	0.2	0.2	0.2	0.2	0.2	L	0.3	0.4	0.4	0.4	0.4	0.5	P	No	No	No
11	m	r	II	0.8	1.1	1.9	2.1	2.3	2.3	0	0.1	0.1	0.3	0.5	0.4	M	0.2	0.3	0.7	0.7	0.7	0.5	P	No	No	No
12	f	l	I	1.2	1.8	2.3	2.8	2.8	3.1	0	0.1	0.1	0	0	0	-	0.2	0.2	0.6	0.7	0.6	0.9	P	0.3	No	No
13	f	r	I	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.1	0.2	0.1	0.2	-	0.2	0.1	0	0	0.1	0	-	No	No	No
14	m	r	I	0.4	0.6	0.7	0.8	0.8	0.9	0.2	0.3	0.4	0.6	0.5	0.4	M	0.2	0.2	0.2	0.1	0.2	0.2	-	No	No	No
15	m	r	I	0.4	0.5	0.6	0.6	0.6	0.6	0	0.1	0.1	0.1	0	0	-	0.1	0.2	0.2	0.2	0.2	0.2	-	No	No	No
16	m	r	I	0.1	0.3	0.4	0.5	0.5	0.5	0.1	0.2	0.2	0.1	0.1	0.1	-	0	0	0.1	0	0	0	-	No	No	No
17	m	l	III	0.5	0.7	0.8	1.1	1.1	1.0	0.2	0	0.1	0	0.2	0.4	L	0.2	0.2	0.3	0.3	0.4	0.6	A	No	0.4	No
18	f	r	I	0.5	0.8	0.7	0.8	0.8	0.8	0.1	0.1	0.1	0.1	0	0.1	-	0.2	0.4	0.2	0.4	0.3	0.3	P	No	No	No
19	f	r	III	0.7	0.9	1.1	1.2	a	1.2	0.2	0.2	0.3	0.6	a	0.9	L	0.3	0.4	0.4	0.4	a	0.6	P	No	No	No
20	f	r	II	2.2	3.5	4.3	5.2	a	6.4	0.3	0.2	0.2	0.2	a	0.2	L	0.8	1.2	1.5	1.9	a	2.3	P	0.6	No	No
21	m	r	II	2.0	2.9	3.8	4.1	4.2	4.2	0.4	0.5	0.6	0.7	1.0	1.0	L	0.1	0.2	0	0	0.1	0	-	No	No	No

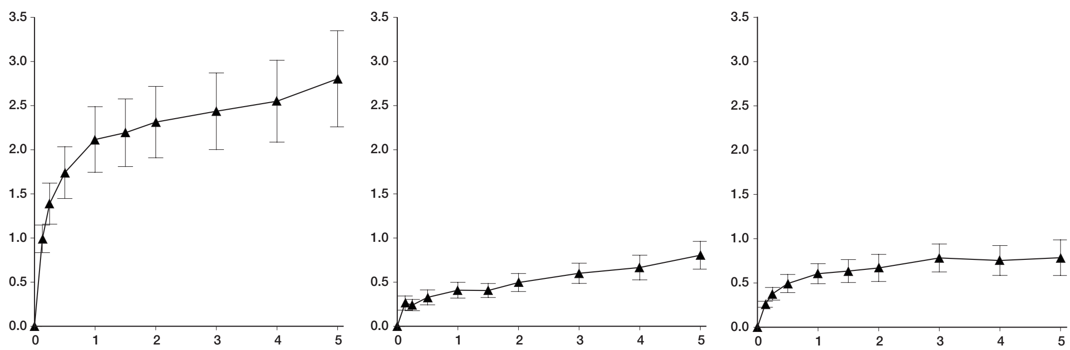
A Patient number
B Gender
C Side
D Bone stock deficiency according to Gustilo and Pasternak (1988)
E Proximal migration between 1.5 and 2 years (No or mm)
F Medial or lateral migration between 1.5 and 2 years (No or mm)
G Posterior or anterior migration between 1.5 and 2 years (No or mm)
a Missed RSA
\- Migration value less than accuracy

Paper VII

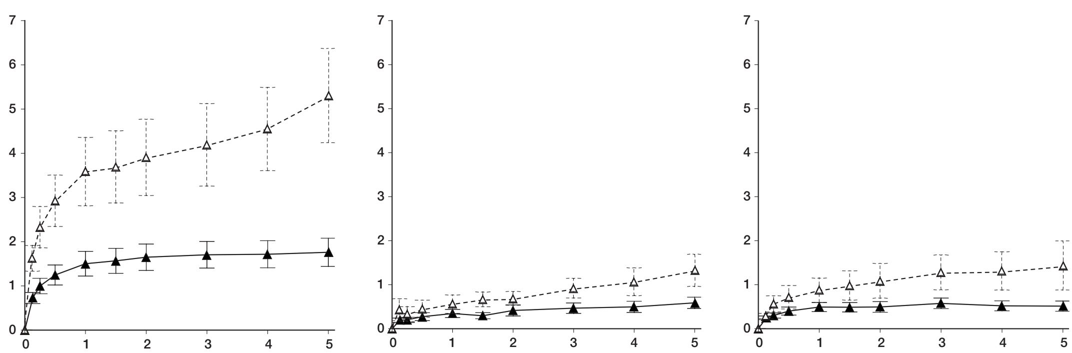
Five years follow-up of socket movements and loosening after revision with impacted morselized allograft bone and cement. A radiostereometric and radiographic analysis



Migration (mm) for each of 17 sockets up to 5 years: proximal migration (left), medial-lateral (middle), posterior (right). Dotted lines represent sockets with radiolucent lines >2 mm in at least 1 zone according to DeLee and Charnley (1976).



Mean (SE) migration (mm) of all 17 sockets up to 5 years: proximal migration (left), medial-lateral (middle), posterior (right).



Mean (SE) socket migration (mm) up to 5 years: proximal migration (left), medial-lateral (middle), posterior (right). Dotted line represents the 5 sockets with a radiolucent line >2 mm in at least 1 zone according to DeLee and Charnley (1976). Unbroken line represents the 12 sockets without a radiolucent line >2 mm in width.

RSA data

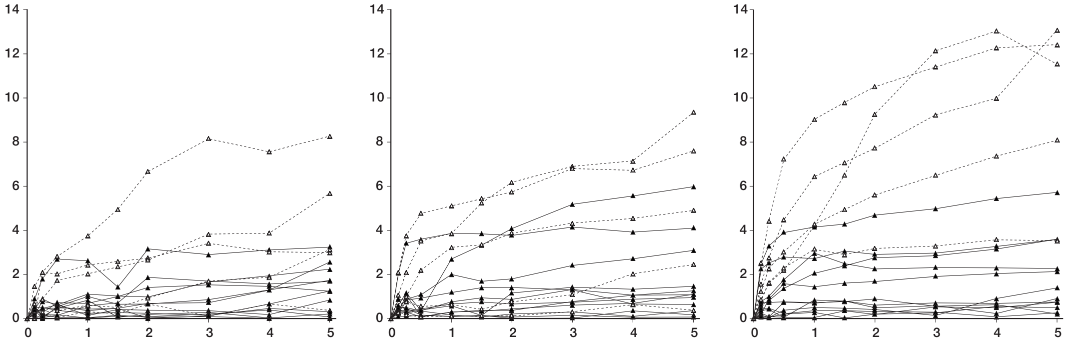
RSA migration (mm) of 17 sockets followed for 5 years

Year	0.13	0.25	0.5	1	1.5	2	3	4	5
Proximal direction (accuracy 0.2 mm)									
1	0.8	1.1	1.2	1.4	1.2	1.5	1.6	1.6	1.7
2	0.3	0.3	0.5	0.7	1.0	1.0	1.1	1.2	1.3
3	1.4	[a]	2.1	2.5	2.4	2.8	2.9	2.9	3.0
4	1.4	2.0	2.7	2.8	2.9	2.9	2.8	2.8	2.7
5	0.6	1.1	1.4	2.7	2.9	3.2	3.4	3.4	3.6
6	1.9	2.5	2.9	3.5	3.9	4.3	4.7	6.1	7.0
7	1.0	1.4	1.7	2.0	2.1	2.2	2.1	2.1	2.1
8	1.1	1.5	1.7	1.9	2.0	1.9	2.0	2.1	2.2
9	0.8	1.2	1.9	2.2	2.3	2.3	2.4	2.4	2.5
10	1.2	1.8	2.3	2.8	2.8	3.1	3.5	3.7	3.9
11	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1
12	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
13	0.2	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.4
14	0.5	0.8	0.7	0.8	0.8	0.8	1.0	1.0	1.0
15	0.7	0.9	1.1	1.3	[a]	1.3	1.6	1.7	2.4
16	2.3	3.6	4.4	5.8	[a]	6.6	7.3	7.1	8.3
17	2.0	2.9	3.8	4.5	4.2	4.2	3.8	4.1	4.9
Medial/lateral direction (accuracy 0.3 mm)									
1	0.5	0.6	0.7	0.7	0.5	0.8	0.8	0.8	0.8
2	0.2	0.3	0.4	0.7	0.7	1.2	1.1	1.1	1.3
3	0.4	[a]	1.1	1.1	0.7	1.2	1.1	1.1	1.2
4	0.1	0	0	0.1	0.1	0.1	0	0.1	0.1
5	0.3	0.1	0.3	0.4	0.5	0.7	0.9	1.2	1.2
6	1.4	0.9	1.1	1.4	1.2	0.9	0.8	1.8	2.1
7	0.1	0.1	0.1	0.1	0.1	0	0.2	0.4	0.5
8	0.5	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.4
9	0	0.1	0.2	0.3	0.4	0.4	0.5	0.5	0.5
10	0	0.1	0.1	0.1	0.2	0.1	0.2	0	0
11	0	0	0.1	0.2	0.2	0.2	0.2	0.4	0.4
12	0	0.1	0.1	0.1	0.1	0	0	0.1	0.1
13	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0	0.3
14	0.1	0.1	0.1	0.1	0	0.1	0.2	0.1	0.1
15	0.2	0.2	0.3	0.5	[a]	0.8	0.8	0.8	1.1
16	0.2	0	0.1	0.3	[a]	0.6	1.3	1.1	1.8
17	0.4	0.5	0.6	0.5	0.9	1.0	1.5	1.6	1.6
Anterior-posterior direction (accuracy 0.4 mm)									
1	0.3	0.5	0.6	0.6	0.6	0.7	0.9	0.8	0.8
2	0	0	0.1	0.1	0.2	0	0.3	0.3	0.3
3	0.4	[a]	0.7	0.9	1.1	1.0	1.0	0.9	1.0
4	0.5	0.6	1.1	1.2	1.1	1.1	1.2	1.1	1.0
5	0.3	0.3	0.5	0.8	1.0	1.2	1.3	1.2	1.2
6	0.3	1.2	1.5	1.7	2.0	2.2	2.4	2.6	3.2
7	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.2	0.1
8	0.3	0.4	0.4	0.4	0.4	0.5	0.4	0.4	0.4
9	0.2	0.2	0.5	0.8	0.4	0.5	0.6	0.4	0.4
10	0.2	0.3	0.6	0.6	0.6	0.8	1.0	0.7	0.8
11	0.2	0.1	0	0.1	0.1	0	0	0.1	0.1
12	0.1	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.2
13	0	0	0.1	0.1	0.1	0	0	0.1	0.1
14	0.3	0.4	0.2	0.4	0.3	0.3	0.6	0.5	0.5
15	0.3	0.4	0.4	0.6	[a]	0.6	0.7	0.9	0.9
16	0.5	0.8	1.1	1.3	[a]	1.8	2.0	2.0	2.2
17	0.1	0.2	0	0.1	0.2	0	0.3	0.3	0.1

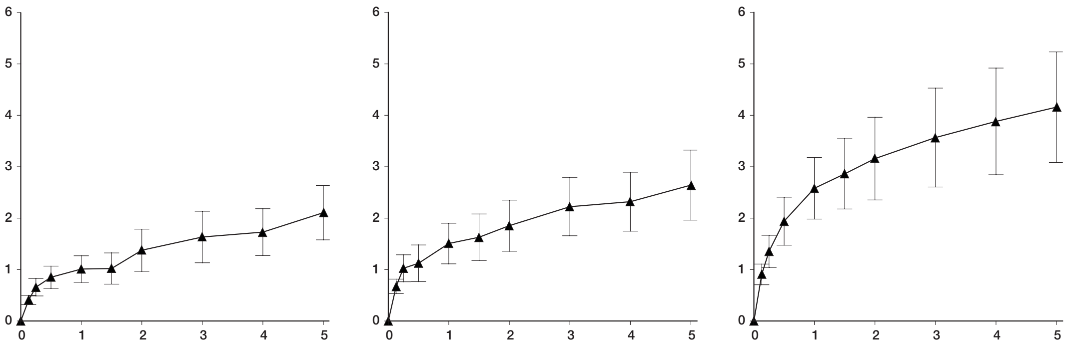
RSA rotation (degrees) of 17 sockets followed for 5 years

Year	0.13	0.25	0.5	1	1.5	2	3	4	5
Anteversion-retroversion (accuracy 2°)									
1	0.2	0.5	0.6	1.1	1.0	1.0	1.7	1.9	2.2
2	0	0	0.2	0.6	0.7	1.9	1.7	1.6	1.7
3	0.9	[a]	2.7	2.6	1.4	3.2	2.9	3.1	3.2
4	0.2	0.8	0.7	0.1	0.4	0.4	0.4	0.2	0.8
5	0.5	0.3	0.7	0.7	1.0	1.4	1.5	1.5	1.2
6	0	2.1	2.8	3.7	5.0	6.7	8.2	7.6	8.3
7	0.5	0.9	0.6	0.4	0.5	0.7	0.7	1.3	2.6
8	0.5	0.2	0.1	0	0.2	0.1	0.1	0	0
9	0.3	0.5	0.5	0.8	0.1	0.2	0.3	0	0.2
10	0.3	0.2	0.1	0.3	0.2	0.7	0.1	0.7	0.4
11	0.4	0	0.5	1.0	0.7	0.7	0.9	1.3	1.7
12	0	0.2	0.2	0	0.1	0.1	0.2	0.4	0.1
13	0.5	0.5	0.4	0.2	0.3	0.2	0.2	0.5	0.3
14	0.5	0.1	0.5	0.4	0.5	0	0.1	0.7	1.3
15	1.5	2.1	2.0	2.4	[a]	2.7	3.4	3.0	3.0
16	0.7	0.9	1.7	2.0	[a]	2.7	3.8	3.9	5.7
17	0	0.3	0.4	0.6	0.5	0.9	1.7	1.9	3.1
Anterior-posterior rotation (accuracy 2°)									
1	0.4	0.9	1.1	2.0	1.7	1.8	2.4	2.7	3.1
2	0.5	0.5	0.3	0.2	0.1	0.2	0.3	0.1	0.4
3	0.4	[a]	0.4	0.6	0.1	1.2	1.4	1.3	1.5
4	2.1	3.4	3.6	3.9	3.8	3.8	4.2	3.9	4.1
5	0.3	0.3	0.4	2.7	3.3	4.1	5.2	5.6	6.0
6	1.1	2.1	3.5	3.9	5.2	6.2	6.9	7.2	9.3
7	0.9	0.8	0.9	1.2	1.4	1.4	1.3	0.7	0.6
8	0.9	0.3	0.1	0.3	0.4	0.4	0.8	1.1	1.3
9	0.2	1.1	0.1	0.3	0.3	0.4	0.6	0.7	1.1
10	0.5	1.0	2.2	3.2	3.3	3.9	4.3	4.5	4.9
11	0.4	0.3	0.4	0.7	0.8	0.7	0.7	0.9	1.0
12	0.1	0.1	0.2	0.1	0.1	0	0	0.4	0.2
13	0.5	0.5	0.2	0.1	0.1	0.1	0.2	0.1	0.1
14	0.6	1.2	0.4	0.8	0.9	0.9	1.3	1.1	1.1
15	0.3	0.2	0.1	0.1	[a]	0.1	0.3	0.6	0.4
16	2.1	3.8	4.8	5.1	[a]	5.7	6.8	6.7	7.6
17	0.3	0.8	0.6	0.6	0.4	0.8	1.1	2.0	2.5
Abduction-adduction (accuracy 1°)									
1	0.7	0.7	0.8	0.7	0.8	0.9	0.6	0.6	0.2
2	0.6	0.8	1.4	2.1	2.4	2.8	2.9	3.2	3.6
3	2.3	[a]	2.8	2.7	3.1	2.9	3.0	3.3	3.6
4	0.2	0.9	1.6	1.4	1.6	1.7	1.9	2.0	2.1
5	0.3	0.1	0.1	0.8	0.8	0.6	0.7	0.7	0.8
6	0.8	1.6	2.2	4.2	6.5	9.3	12.1	13	11.5
7	0.4	0.4	0	0.1	0.4	0.2	0.5	0.5	0.7
8	2.5	3.3	3.9	4.2	4.3	4.7	5.0	5.4	5.7
9	0.8	1.0	1.8	3.0	2.5	2.3	2.3	2.3	2.3
10	0.9	1.6	2.3	3.1	2.9	3.2	3.3	3.6	3.5
11	0.2	0.1	0.2	0.3	0	0.2	0.3	0.6	0.5
12	0.5	0.5	0.2	0.4	0.4	0.3	0.3	0.1	0.3
13	0.1	0.1	0.7	0.7	0.8	0.5	0.6	0.2	0.9
14	0.1	0.1	0.4	0.5	0.5	0.4	0.1	0.9	1.4
15	1.6	2.7	4.5	6.4	[a]	7.7	9.2	10	13
16	1.2	2.3	3.0	4.3	[a]	5.6	6.5	7.4	8.1
17	2.5	4.4	7.2	9.0	9.8	10.5	11.4	12.3	12

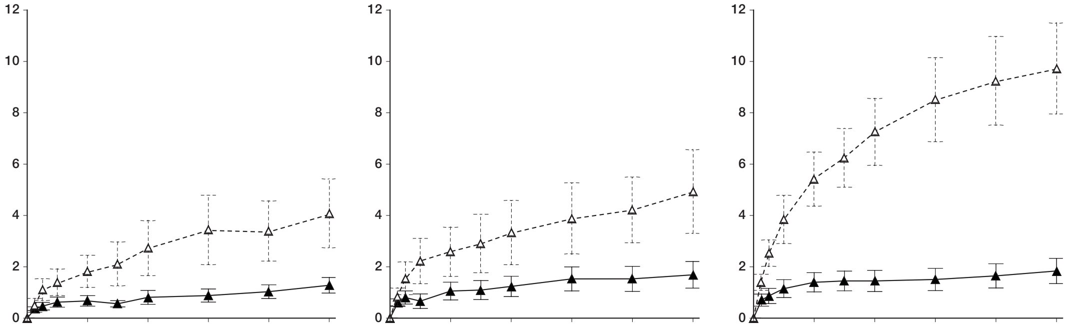
[a] missed RSA.



Rotation (degrees) for each of 17 sockets up to 5 years: anteversion-retroversion (left), anterior-posterior rotation (middle), abduction-adduction (right). Dotted lines represent sockets with radiolucent lines >2 mm in at least 1 zone according to DeLee and Charnley (1976).



Mean (SE) rotation (degrees) of all 17 sockets up to 5 years: anteversion-retroversion (left), anterior-posterior rotation (middle), abduction-adduction (right).



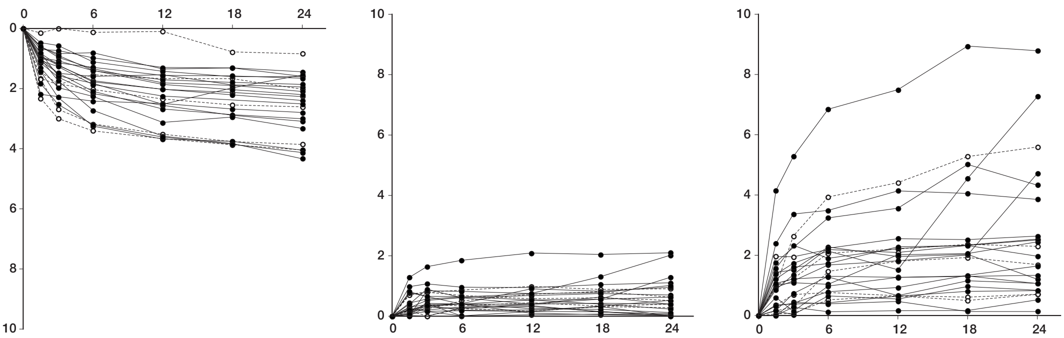
Mean (SE) socket rotation (degrees) up to 5 years: anteversion-retroversion (left), anterior-posterior rotation (middle), abduction-adduction (right). Dotted line represents the 5 sockets with a radiolucent line >2 mm in at least 1 zone according to DeLee and Charnley (1976). Unbroken line represents the 12 sockets without a radiolucent line >2 mm in width.

Data before and 5 years after 17 Exeter socket revisions with impacted morselized allograft bone and cement.

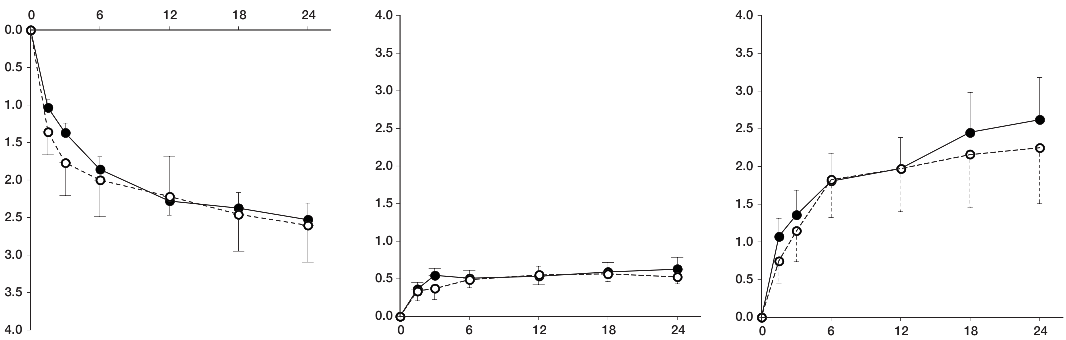
Case	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Gender	M	F	F	F	M	F	F	F	M	F	F	M	M	F	F	F	M
Side	R	L	R	R	L	R	L	L	R	L	R	R	R	R	R	L	R
Age at surgery	80	76	79	78	75	81	56	71	69	72	70	77	62	60	78	73	81
Weight (kg)	85	71	70	50	68	56	97	45	95	78	74	94	45	71	71	81	75
Patient category	II	I	III	II	II	II	III	II	II	II	III	II	II	II	II	II	II
Bone stock deficiency	III	III	III	III	II	III	II	II	II	I	I	I	I	I	III	II	II
Pain preoperatively	1	4	3	3	3	4	1	2	1	4	6	4	3	3	2	3	3
Pain	6	6	6	6	4	6	5	6	5	4	6	5	6	6	6	4	6
Walking ability preoperatively	3	4	1	2	4	4	5	1	4	3	4	1	5	2	1	2	5
Walking ability	4	6	2	2	4	4	4	6	3	4	4	4	6	2	2	4	2
ROM preoperatively	6	5	5	5	4	5	5	3	3	5	5	4	3	5	4	4	4
ROM	5	5	4	5	4	4	4	6	3	4	5	5	5	3	4	5	5
Migration between 4 years and 5 years	-	-	-	-	-	Yes	-	-	-	-	-	-	-	-	Yes	Yes	Yes
Rotation between 4 years and 5 years	-	-	-	-	-	Yes	-	-	-	-	-	-	-	-	Yes	-	-
Radiolucent line zone I	-	-	-	-	-	>2	-	-	-	>2	-	-	-	-	>2	>2	-
Radiolucent line zone II	-	-	-	-	-	-	-	-	-	>2	-	-	-	-	>2	>2	-
Radiolucent line zone III	-	-	-	-	-	>2	-	-	-	>2	-	-	-	-	>2	>2	>2
Radiographic Loose or Stable	S	S	S	S	S	L	S	S	S	L	S	S	S	S	L	L	L
Graft resorption zone I	-	-	-	-	-	Yes	-	-	-	Yes	-	-	-	-	Yes	Yes	Yes
Graft resorption zone II	-	-	-	-	-	Yes	-	-	Yes	Yes	-	-	-	-	Yes	Yes	Yes
Graft resorption zone III	-	-	Yes	-	-	Yes	-	-	-	Yes	-	-	-	-	-	Yes	-
Trabecular remodeling zone I	-	-	-	Yes	-	-	-	-	-	-	-	-	-	-	-	-	-
Trabecular remodeling zone II	-	Yes	-	Yes	-	-	-	-	-	-	-	-	-	-	-	-	-
Trabecular remodeling zone III	-	-	-	-	-	-	-	-	Yes	-	-	-	-	-	-	-	-
Trabecular incorporation zone I	Yes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trabecular incorporation zone II	Yes	Yes	Yes	-	-	Yes	-	-	-	-	-	-	Yes	-	-	-	-
Trabecular incorporation zone III	-	-	-	Yes	-	-	-	Yes	-	-	-	-	-	-	-	-	-

Paper VIII

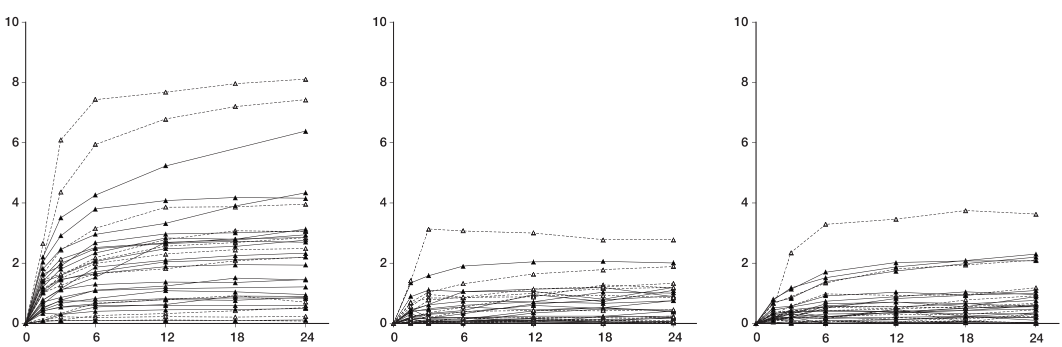
Hip revisions with impacted morselized allografts: unrestricted weight bearing and restricted weight bearing has similar effect on migration. A radiostereometry analysis



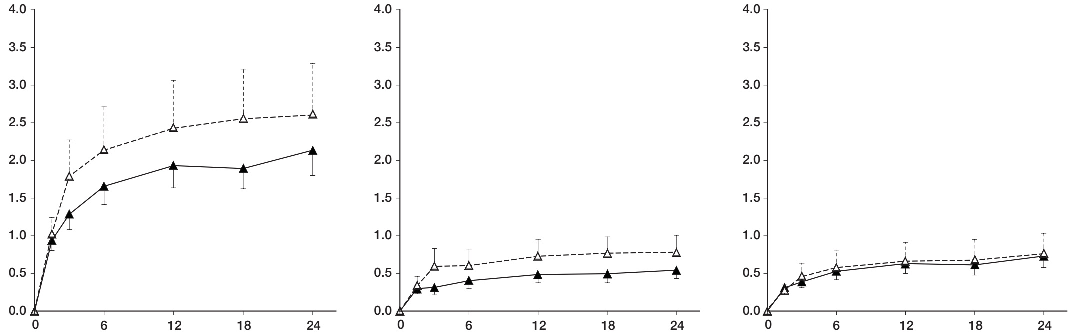
Migration (mm) for each of 25 stems up to 24 months: distal migration (left), medial-lateral (middle), posterior-anterior (right). Dotted lines represent patients who practiced unrestricted weight bearing immediately after revision (6 stems, 1 outlier excluded). Unbroken lines represent patients who practiced restricted weight bearing for 3 months after revision (the same 18 stems as in study IV).



Mean (SE) stem migration (mm) up to 24 months: distal migration (left), medial-lateral (middle), posterior-anterior (right). Dotted line and unbroken line, see legend above.



Socket migration (mm) for each of 33 sockets up to 24 months: proximal migration (left), medial-lateral (middle), posterior-anterior (right). Dotted lines represent patients who practiced unrestricted weight bearing immediately after revision (12 hips), unbroken lines represent patients who practiced restricted weight bearing for 3 months after revision (the same 21 hips as in study VI).



Mean (SE) socket migration (mm) up to 24 months: proximal migration (left), medial-lateral (middle), posterior-anterior (right). Dotted line represents patients who practiced unrestricted weight bearing immediately after revision (12 sockets). Unbroken line represents patients who practiced restricted weight bearing for 3 months after revision (the same 21 sockets as in study VI).

Migration of 7 stems and 12 sockets revisions with morselized allografts and cement, unrestricted weight bearing, accuracy values for paper IV and paper VI used. Stem number 6 outlier

A	B	C	D	Distal migration (mm)						Medial or lateral migration (mm)							Posterior or anterior migration (mm)							E	F	G
				1.5	3	6	12	18	24	1.5	3	6	12	18	24		1.5	3	6	12	18	24	months after revision			
Stems																										
1	f	R	II	0.9	1.2	1.7	2.0	2.1	2.3	0.0	0.0	0.3	0.4	0.4	0.4	-	1.0	2.6	3.9	4.4	5.3	5.6	P	No	No	No
4	f	R	II	1.7	1.9	1.5	1.7	1.7	2.0	0.2	0.2	0.5	0.7	0.8	0.6	L	0.2	0.3	1.5	1.8	1.9	1.7	P	0.3	No	No
5a	f	L	II	1.4	1.8	2.0	2.3	2.5	2.6	0.2	0.4	0.3	0.4	0.3	0.4	-	0.3	0.7	0.8	0.7	0.6	0.7	P	No	No	No
6	f	L	II	4.8	11.3	15.0	17.9	19.1	16.5	2.7	5.1	5.0	4.7	4.6	4.2	L	4.7	15.8	19.3	19.1	19.9	22.1	P	2.6	No	2.2
8	m	R	II	1.7	2.7	3.2	3.5	3.8	3.9	0.2	0.0	0.3	0.2	0.3	0.3	-	1.0	1.2	2.1	2.2	2.4	2.3	P	No	No	No
12	m	R	II	2.3	3.0	3.4	3.7	3.9	4.0	0.7	0.8	0.7	0.6	0.6	0.5	L	2.0	2.0	2.2	2.1	2.3	2.5	P	No	No	No
13b	f	L	I	0.1	0.0	0.1	0.1	0.8	0.8	0.7	0.8	0.9	1.0	0.9	0.9	M	0.1	0.1	0.5	0.6	0.5	0.7	P	No	No	0.7
A	B	C	D	Proximal migration (mm)						Medial or lateral migration (mm)							Posterior or anterior migration (mm)							F	G	H
Sockets																										
1	f	R	II	1.6	2.4	3.2	3.9	3.9	4.0	0.7	1.0	1.3	1.6	1.8	1.9	L	0.2	0.2	0.2	0.5	0.0	0.3	P	No	No	0.3
2c	f	R	II	d	0.1	0.3	0.3	0.4	0.5	d	0.1	0.2	0.2	0.2	0.2	-	d	0.2	0.2	0.3	0.3	0.5	P	No	No	0.5
3	f	L	II	d	d	0.7	0.8	0.9	0.7	d	d	0.1	0.17	0.1	0.0	-	d	d	0.1	0.1	0.1	0.0	-	0.2	No	No
4	f	R	II	2.7	6.1	7.4	7.7	8.0	8.1	1.4	3.1	3.1	3.0	2.8	2.8	M	0.5	2.4	3.3	3.5	3.7	3.6	P	No	No	No
5a	f	L	II	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.1	0.1	0.2	-	0.1	0.1	0.1	0.0	0.1	0.0	-	No	No	No
6	f	L	II	1.0	1.6	2.2	2.8	3.1	3.0	0.2	0.4	0.5	0.9	0.9	0.9	L	0.7	0.9	1.3	1.8	1.9	2.1	P	No	No	No
7	m	R	II	1.0	1.3	1.7	1.8	2.1	2.2	0.1	0.1	0.1	0.1	0.1	0.1	-	0.4	0.4	0.5	0.5	0.8	0.9	P	No	No	No
9	f	R	I	1.4	1.6	2.1	2.6	2.7	2.9	0.7	0.8	0.8	1.0	1.2	1.2	L	0.2	0.0	0.0	0.1	0.2	0.2	-	No	No	No
10	f	R	II	1.5	2.1	2.5	2.7	2.8	2.9	0.6	1.0	0.9	0.9	1.3	1.2	L	0.2	0.4	0.6	0.6	0.5	0.6	P	No	No	No
11	f	R	II	d	4.4	5.9	6.8	7.2	7.4	d	0.8	0.9	1.1	1.2	1.3	L	d	0.6	1.0	0.9	1.0	1.2	P	0.2	No	No
12	m	R	II	1.2	1.5	2.0	2.3	2.5	2.5	0.2	0.2	0.4	0.4	0.4	0.5	L	0.3	0.4	0.4	0.5	0.6	0.7	P	No	No	No
13	f	L	III	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	-	0.1	0.1	0.0	0.2	0.1	0.3	A	No	No	0.3

A Patient number
B Gender
C Side
D Bone stock deficiency accdoring to Gustilo and Pasternak (1988)
E Distal migration between 1.5 and 2 years (No or mm)
F Medial or lateral migration between 1.5 and 2 years (No or mm)
G Posterior or anterior migration between 1.5 and 2 years (No or mm)
H Proximal migration between 1.5 and 2 years (No or mm)
a Patient with femoral head dislocation
b Plating due to femoral shaft fracture the day after surgery
c Stem revision due to femoral shaft fracture 3 weeks after surgery
d Missed RSA
\- Migration value less than accuracy