Department of Orthopaedics and Traumatology
Helsinki University Central Hospital
University of Helsinki

and

ORTON Orthopaedic Hospital
Helsinki, Finland

# Total Hip Arthroplasty in Young Patients – with special references to patients under 55 years of age and to patients with developmental dysplasia of the hip

**Antti Eskelinen**

***Academic dissertation***

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**Supervised by:**
Docent Ville Remes, M.D., Ph.D.
Department of Orthopaedics and Traumatology, Helsinki University Central Hospital
University of Helsinki, Finland

Professor Pekka Paavolainen, M.D., Ph.D.
ORTON Orthopaedic Hospital and
University of Helsinki, Finland

**Reviewed by:**
Docent Juhana Leppilahti, M.D., Ph.D.
Department of Orthopaedics and Traumatology, Oulu University Hospital and
University of Oulu, Finland

Docent Jorma Pajamäki, M.D., Ph.D.
Coxa Hospital for Joint Replacement and
University of Tampere, Finland

**Discussed with:**
Docent Hannu Miettinen, M.D., Ph.D.
Department of Orthopaedics and Traumatology, Kuopio University Central Hospital and
University of Kuopio

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*To Elina*
*To my family*

# 1. CONTENTS

# 2. LIST OF ORIGINAL PUBLICATIONS

The present thesis is based on the following original papers, which will be referred to in the text by their Roman numerals:

I Eskelinen A, Remes V, Helenius I, Pulkkinen P, Nevalainen J, Paavolainen P. Total hip arthroplasty for primary osteoarthrosis in younger patients in the Finnish Arthroplasty Register – 4661 primary replacements followed for 0-22 years. Acta Orthop 2005; 76: 28-41.

II Eskelinen A, Remes V, Helenius I, Pulkkinen P, Nevalainen J, Paavolainen P. Uncemented total hip arthroplasty in young patients – a mid-to long-term follow-up study from the Finnish Arthroplasty Register. Acta Orthop 2006; 77: 57-70.

III Eskelinen A, Paavolainen P, Helenius I, Pulkkinen P, Remes V. Total hip arthroplasty for rheumatoid arthritis in younger patients. 2557 replacements in the Finnish Arthroplasty Register followed for 0-24 years. Acta Orthop (In press).

IV Eskelinen A, Helenius I, Remes V, Ylinen P, Tallroth K, Paavilainen T. Uncemented total hip arthroplasty in patients with high congenital hip dislocation. J Bone J Surg Am 2006; 88: 80-91.

V Eskelinen A, Remes V, Helenius I, Ylinen P, Tallroth K, Paavilainen T. Uncemented total hip arthroplasty in patients with severely dysplastic hips and a previous Schanz osteotomy of the femur. Submitted.

# 3. ABBREVIATIONS

| | | |
|---|---|---|
| DDH | = | developmental dysplasia of the hip |
| HA | = | hydroxyapatite |
| HHS | = | Harris hip score |
| JCA | = | juvenile chronic arthritis |
| LFA | = | low-friction arthroplasty |
| OA | = | osteoarthritis |
| PE | = | polyethylene |
| RA | = | rheumatoid arthritis |
| RR | = | revision risk ratio |
| THA | = | total hip arthroplasty |
| THR | = | total hip replacement |
| UHMWPE | = | ultra-high molecular weight polyethylene |

# 4. ABSTRACT

**Introduction:** There is an ongoing controversy as to which methods in total hip arthroplasty (THA) could provide young patients with best long-term results. THA is an especially demanding operation in patients with severely dysplastic hips. The optimal surgical treatment for these patients also remains controversial.

**Aims of the present study:** The aim of this study was to evaluate the long-term survival of THA in young patients (<55 years at the time of the primary operation) on a nation-wide level, and to analyze the long-term clinical and radiographical outcome of cementless THA in patients with severely dysplastic joints.

**Methods:**

1. A total of 4661 primary THAs, performed for primary osteoarthritis (OA) in patients under 55 years of age and entered between 1980 and 2001 in the Finnish Arthroplasty Register, were subjected to analysis.
2. Survival of uncemented THA designs, which had been used in more than 100 operations, performed for primary OA in patients under 55 years of age and entered between 1980–2003 in the Finnish Arthroplasty Register, were analyzed.
3. A total of 2557 primary THAs, performed for rheumatoid arthritis (RA) in patients under 55 years of age and entered in the Finnish Arthroplasty Register between 1980–2003, were analyzed.
4. Between 1989-1994, 68 THAs were performed at Orton Orthopaedic Hospital in 56 consecutive patients with high congenital hip dislocation. The patients underwent a detailed physical and radiographical evaluation at a mean of 12.3 years postoperatively.
5. Between 1988-1995, 68 THAs were performed at Orton Orthopaedic Hospital in 59 consecutive patients with severely dysplastic hips and a previous Schanz osteotomy of the femur. At a mean of 13.0 years postoperatively, 58 patients (67 hips) were evaluated with a detailed physical and radiographical examination.

**Results:**

1. The risk of stem revision due to aseptic loosening in young patients with primary OA was higher for cemented stems than for proximally porous-coated or HA-coated uncemented stems implanted over the 1991–2001 period. The risk of revision for all-poly cemented-cups implanted during the same period was higher than that for press-fit porous-coated uncemented-cups when aseptic loosening was used as the end point. However, there was no longer any difference in the risk between these two design concepts when the end point was defined as any revision (including exchange of liner).
2. All uncemented stem designs studied in young patients with primary OA had over 90% survival rate at 10 years. The Biomet Bi-Metric stem had a 95% (95% CI 93–97) survival rate even at 15 years. The Biomet Universal, the ABG Il and the Harris-Galante II cups

had >90% survival rates at 10 years when aseptic loosening was used as the end point. When the end point was defined as any revision (incl. exchange of liner), 10 year survival rates of all cup brands except the Harris-Galante II decreased to less than 80%.

3. In young patients with RA, the risk of stem revision due to aseptic loosening was higher with cemented stems than with proximally porous-coated uncemented stems. In contrast, the risk of cup revision was significantly higher for all uncemented cup concepts than for all-poly cemented cups with any type of cup revision as the end point.
4. In patients with high congenital hip dislocation treated with cementless THA, the Harris hip score increased significantly ($p<0.001$). There was a negative Trendelenburg sign in 92% of hips. There were 12 perioperative complications (18%). With revision because of aseptic loosening as the end point, the 10 year survival rate was 95% (95% CI 89–100) for press-fit, porous-coated acetabular components and 98% (95% CI 97–100) for the CDH femoral component.
5. Cementless THA led to a significant increase of the Harris hip score in patients with severely dysplastic hips and a previous Schanz osteotomy. There was a negative Trendelenburg sign in 88% of hips. There were 15 perioperative complications (22%). The 10 year survival rate for press-fit, porous-coated acetabular components was only 69% (95% CI, 56–82) with revision of the cup for any reason as the end point. The rate of survival for the CDH femoral components, with revision due to aseptic loosening as the end point, was 92% (95% CI, 86–99) at 14 years.

**Conclusions:**

1. For young patients with primary OA, uncemented proximally circumferentially porous- and HA-coated stems are the implants of choice. However, survival rates of modern uncemented cups are no better than that of all-poly cemented cups.
2. Modern second-generation uncemented stem designs seem to be a good choice for young patients with primary OA. Survival rates of uncemented cup designs were unsatisfactorily low because of multiple liner revisions.
3. Uncemented proximally circumferentially porous-coated stems and cemented all-poly cups are currently the implants of choice for young patients with RA.
4. Uncemented THA, with placement of the cup at the level of the true acetabulum, distal advancement of the greater trochanter and femoral shortening osteotomy provided patients with high congenital hip dislocation good long-term outcomes. Numerous cup revisions were secondary to sub-optimal design of the acetabular component used in this series.
5. Most of the patients with severely dysplastic hips and a previous Schanz osteotomy can be successfully treated with uncemented THA, combined with transposition of the greater trochanter and femoral shortening osteotomy. However, the subtrochanteric segmental shortening with angular correction gives better leg length correction for the patients with a previous low-seated unilateral Schanz osteotomy.

# 5. Introduction

Due to higher demands of the population and the better long-term results of total hip arthroplasty (THA), the proportion of younger and more active patients treated with this procedure has increased steadily. A good long-term outcome (≥90% 10 year survival rate) (NICE 2003) has been reported for patients under 55 years of age for cemented (Boeree and Bannister 1993, Joshi et al. 1993, Emery et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a) and uncemented (Fye et al. 1998, Kim et al. 2003b) THAs. However, the majority of these reports has originated from highly specialized clinics and refer to only one implant brand (Joshi et al. 1993, Emery et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Kim et al. 2003b). Despite the good results obtained for modern uncemented implants in these patients, some authors still consider the use of uncemented implants in THA as experimental (Thanner et al. 1999, Havelin et al. 2000). Only a few register-based studies have reported the results of THA in young patients on a population-based level (Havelin et al. 2000, Malchau et al. 2002). Most of the previous studies report a higher risk of revision in younger patients than in older patients (Herberts and Malchau 2000, Furnes et al. 2001).

Only a few studies reported the long-term outcome of THA for young patients with rheumatoid arthritis (RA). Good results were reported for both uncemented (Keisu et al. 2001, Lyback et al. 2004) and cemented (Lehtimaki et al. 1997, Creighton et al. 1998, Lehtimaki et al. 1999) femoral components. However, loosening of the acetabular component remains a major long-term problem after THA in patients with RA (Katsimihas et al. 2003). Population-based results of THA in young patients with RA have not been published.

Published reports of THA in patients with congenital hip disease include all three subtypes of the disease: dysplasia, low dislocation, and high dislocation (Harris et al. 1977, Garvin et al. 1991, DiFazio et al. 2002, Perka et al. 2004). These three factors have confounded efforts to analyze the results. Only three studies have reported the results of THA in patients with high congenital hip dislocation (Hartofilakidis et al. 1998, Hartofilakidis and Karachalios 2004, Lai et al. 2005). Hartofilakidis et al. (2004) reported good long-term results after cemented THA in 84 patients. Lai et al. (2005) reported the results of uncemented THA in 56 patients; the Harris hip score (HHS) values increased, an uncemented stem had a 100% survival rate at 12 years, but uncemented cups had only a 77% survival rate at 12 years

In 1922, Schanz published the technique for subtrochanteric osteotomy of the femur of young adults with high congenital hip dislocation (Schanz 1922). The purpose of the procedure was to reduce the severity of limping and to allow greater abduction and flexion. As early attempts to reconstruct the hips of adults who had a high congenital dislocation were unsuccessful, and some authors considered high hip dislocation to be a contra-indication to total hip replacement (Charnley and Feagin 1973, Eftekhar 1978), the Schanz osteotomy was generally used at our institution until the 1970's.

For high congenital hip dislocation THA is a technically demanding operation owing to the associated anatomical abnormalities encountered (Hartofilakidis et al. 1996, Hartofilakidis and Karachalios 2000). However, the anatomy is even more altered and variable on both the femoral and pelvic sides of the hip after a Schanz osteotomy (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997). In particular, identification and preparation of the true acetabulum, preparation of the femoral canal, and stable reduction of the components pose several technical problems.

There are only four previous reports on THA in patients who have previously undergone a Schanz osteotomy (Paavilainen et al. 1990, Paavilainen et al. 1993, Perka et al. 2000, Sener et al. 2002). In all of these studies, those patients with a previous Schanz osteotomy have only been a small subgroup of the population. To our knowledge, there are no reports on THA only, in patients with a previous Schanz osteotomy.

The aims of this study were to evaluate the long-term survival of THA in young patients (<55 years) with primary OA and RA on a nation-wide level using the data of the Finnish Arthroplasty Register. Further, to analyze the long-term clinical and radiographical outcomes of cementless THA in young patients with severely dysplastic joints operated on in the Orthopaedic Hospital of the Invalid Foundation, Helsinki, Finland.

# 6. REVIEW OF LITERATURE

## 6.1 Epidemiology of total hip arthroplasty in young patients

Most of the patients undergoing THA are women and the mean age of the patients at the time of the operation is ca. 70 years (Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, Nevalainen 2004, NAR 2005, SOS 2005). Primary OA is the most common indication for THA. It accounts for 70–90% of primary operations (Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, Nevalainen 2004, NAR 2005, SOS 2005). This is followed by femoral neck fractures (3–13%), RA (2–7%), and developmental dysplasia of the hip (DDH) (2–8%) (Table 1) (Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, Nevalainen 2004, NAR 2005, SOS 2005). In younger patients, commonly referred to as patients less than 50-60 years of age, the diagnoses profile leading to THA differ in proportion from older patients (Table 1). Primary OA is still the most common diagnosis. However, RA and DDH are clearly more often the reason for THA in younger patients than among older patients. However, a small proportion of the patients diagnosed with OA may in fact have mild DDH in young patients (Harris 1986). The proportion of males is higher among younger patients undergoing THA than among older patients (Table 1) (Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, Nevalainen 2004, NAR 2005, SOS 2005).

An increase in incidence of THA in younger patients during the last 10–15 years has been recorded in several national arthroplasty registers (DHR 2004, Nevalainen 2004, NAR 2005, SOS 2005). Over the same period there was no change in the incidence of hip OA (Danielsson and Lindberg 1997). This may reflect the increase in health services capable of offering THA for patients in need. Moreover, the inclusion criteria for THA may have relaxed, while the technology associated with THA has developed markedly, and expectations of patients have also grown.

**Table 1.** Epidemiological factors of THA in national arthroplasty registers.

| | | Indication for THA | | | |
|---|---|---|---|---|---|
| **Country** | **THA incidence[a]** | **Primary OA** | **RA** | **DDH** | **Women** |
| *All patients* | | | | | |
| Finland [b] | 93 | 78% | 7% | 2% | 62% |
| Sweden [c] | 125 | 76% | 5% | 2% [d] | 61% |
| Norway [e] | 120 | 71% | 3% | 8% | 69% |
| Denmark [f] | 110 | 76% | 3% | 2% | 59% |
| Australia [g] | 93 | 88% | 2% | 2% | 55% |
| *Younger patients* [h] | % of all | | | | |
| Finland [i] | 14% | 44% | 20% | 8% | 56% |
| Sweden [j] | 5% | 54% | 17% | 14% [d] | NA |
| Norway [k] | 17% | 42% | 6% | 29% | 62% |
| Denmark [l] | 6% | 45% | 7% | NA | 43% |
| Australia [m] | 15% | NA | NA | NA | <50% |

[a] Incidence of primary THA per 100 000 inhabitants. Percentage of younger patients of all patients undergoing THA.
[b] Diagnoses during 1980 – 2003. Incidence of primary THA in 1999.
[c] Diagnoses during 1992 – 2004. Incidence of primary THA in 2000.
[d] Includes all childhood diseases
[e] During 1987 – 2004.
[f] During 1995 – 2003. Incidence of THR in 2003 estimated from a diagram.
[g] Diagnoses during 1999 – 2003. Incidence of primary THA during 2001-2003.
[h] Percentage of younger patients of all patients undergoing THA.
[i] Patients under 55 years of age
[j] Patients under 50 years of age
[k] Patients aged 60 years or under. Calculated from a table in a published study (Furnes et al. 2001).
[l] Patients aged 40-49 years. Estimation from a diagram.
[m] Patients under 50 years of age. Estimated from a diagram (AOA 2004).

OA = osteoarthritis. RA = rheumatoid arthritis. DDH = developmental dysplasia of the hip. NA = not available

### 6.1.1 Primary osteoarthritis

Osteoarthritis of the hip is a painful disease that causes a lot of disability. It has been estimated that in the U.S.A., 12% of the population aged over 25 years have clinical signs and symptoms of hip OA (Lawrence et al. 1998). Hip OA can result from several different patterns of joint failure. Underlying pathological changes due to conditions such as osteonecrosis, trauma, sepsis, Paget's disease and RA can result in degeneration of the joint. Anatomical abnormalities such as DDH or slipped capital femoral epiphysis can later result in osteoarthritic changes. In about 70% of patients undergoing THA, neither an anatomical abnormality nor any specific disease can be identified (Havelin et al. 2000, Puolakka et al. 2001b, Malchau et al. 2002), and the condition is called *primary OA*, a diagnosis made by exclusion of the causes mentioned above.

On the other hand, Harris (1986) originally hypothesized that the majority of patients diagnosed with primary OA would in fact have mild DDH and/or pistol grip deformity of the hip. Recent studies support this hypothesis. In a systematic review, Lievense and colleagues (2004) concluded, that there is limited evidence for a positive association between hip dysplasia and hip OA. Similarly, Lane et al. (2000) found that acetabular dysplasia, as defined by a decrease in the center-edge angle, is associated with a modestly increased risk of incident hip OA in elderly white women. The relation between DDH and hip OA or hip complaints seems to be much higher in younger age groups (Dudkiewicz et al. 2002).

The diagnosis of hip OA is based on hip radiographs. In milder cases, conservative treatment, i.e. physiotherapy, non-steroidal anti-inflammatory detergents (NSAIDs), alleviates the symptoms. In more severe cases, THA has been the treatment of choice since the 1960s (Charnley 1979).

Several probable risk factors for primary OA of the hip have been identified in epidemiological studies: older age (Havelin et al. 1993), male gender (Havelin et al. 1993), high BMI (Oliveria et al. 1999), previous hip injury (Cooper et al. 1998), sports activity (Lindberg et al. 1993, Vingard et al. 1993) and physical activity in work (Vingard et al. 1991, Croft et al. 1992a, Coggon et al. 1998). Results from a sibling study suggested, that hip OA has a strong genetic component (Lanyon et al. 2000). In a cohort study of 50 304 patients, Flugsrud and colleagues (2002) found that the most important risk factors for THA due to primary OA were high BMI and intensive physical activity at work.

### 6.1.2 Rheumatoid arthritis

Recent epidemiological studies report the incidence of RA at about 50/100 000 inhabitants (Chan et al. 1993, Kaipiainen-Seppanen et al. 1996, Wiles et al. 1999). Other studies suggest the prevalence of RA is about 1% in the adult population (Hazes and Silman 1990, Hakala et al. 1993), which implies that there are about 50 000 patients with RA in Finland at the moment (Hakala et al. 1993).

Hip problems are encountered in 20–40% of patients with RA (Konttinen et al. 2000), and THA is the most common major operation for these patients (Konttinen et al. 2000). It has been estimated that based on data from the Finnish Arthroplasty Register the annual need for THA due to RA is 10/100 000 inhabitants in Finland (Konttinen et al. 2000). In Norway, the incidence of THA for RA has been reported to be about 6/100 000 and in Sweden 6.5/100 000 (Havelin et al. 2000, Malchau et al. 2002). The incidence of THA for RA decreased by 35% in Finland over the 1987–1997 period, whereas the incidence of THA for primary OA increased by 67% for the same period (Konttinen et al. 2000). The reason for this change may be the improved conservative treatment for RA. This involves simultaneous therapy with multiple disease-modifying anti-rheumatic drugs (DMARDs) as well as the use of more aggressive treatment measures in the early phases of disease, which became more common during the 1990's (Mottonen et al. 1999a, Mottonen et al. 1999b).

It is typical of RA that the progression of the disease varies a lot. A severe form of RA can even destroy the hip joint in just a few months. In contrast, the pathology of joint destruction is slower in primary OA and much easier to predict (Konttinen et al. 2000). In five years from the onset of RA

symptoms, about 10% of the RA patients need THA (Poss et al. 1984, Lehtimaki et al. 1986, Eberhardt et al. 1990, Havelin et al. 1993, Malchau et al. 1993, Eberhardt et al. 1995, Lehtimaki et al. 1998). In patients with juvenile chronic arthritis (JCA), rapidly progressive joint destruction can lead to THA at a very young age. In clinical studies, the mean age range of patients undergoing THA was 28–32 years (Lehtimaki et al. 1997, Lyback et al. 2004). These factors explain, why patients undergoing THA for RA are younger than patients on whom THA is performed for primary OA (AOA 2004, Nevalainen 2004, NAR 2005, SOS 2005).

## 6.1.3 Developmental dysplasia of the hip

### 6.1.3.1 Aetiology and epidemiology

The aetiology of DDH is multifactorial, involving both genetic and intrauterine environmental factors (Ryöppy 1997). The overwhelming majority of cases are detectable at birth (Hansson et al. 1983, Cates et al. 1993). Despite newborn screening programmes, some cases are missed. The at-risk group of patients includes those with any combination of the following risk factors: breech delivery, oligohydramnios, female gender, first born, positive family history or ethnic background, persistent hip asymmetry (e.g., abduction of one hip and adduction of the other), torticollis, and lower-limb deformity (Weinstein 2001).

Prevalence of DDH varies from 0 to 20% in different populations (Ryöppy 1997). At the moment, the incidence of DDH is about 70/1000 in newly born children in Finland (Ryöppy 1997).

### 6.1.3.2 Progression of hip disease in untreated patients with developmental dysplasia

The natural progression of hip disease in untreated complete dislocations depends on two factors: the degree of bilateral involvement and the development or lack of development of a false acetabulum (Wedge and Wasylenko 1978, Weinstein 1987, Hartofilakidis et al. 2000). Patients with bilateral untreated high dislocation without a false acetabulum have a good range of motion and no pain. However, hyperlordosis and low back pain develop over time. If the completely dislocated femoral head articulates with the ilium and the patient has a false acetabulum, secondary degenerative arthritis will develop in the false acetabulum (Wedge and Wasylenko 1978, Weinstein 1987, Hartofilakidis et al. 2000).

Whether a patient with an untreated unilateral complete dislocation has pain depends on the development or lack of development of a false acetabulum. Other associated problems in such patients include limb-length inequality, which can be major (up to 10 cm); ipsilateral valgus knee deformity with attenuation of the medial collateral ligament; degenerative changes in the lateral knee compartment; gait disturbance; and secondary scoliosis (Weinstein 1987, Hartofilakidis et al. 2000).

The natural progression of hip disease in patients with a low dislocation is clear; degenerative joint disease will develop in all patients, usually in the third or fourth decade of life (Weinstein 1987, Hartofilakidis et al. 2000). Moreover, dysplasia usually leads to degenerative joint disease in adult age, particularly in females (Harris 1986, Schwend et al. 1999). The natural progression of hip disease in adults with an untreated

dysplasia or a low dislocation is equal to residuals of these conditions after treatment in childhood (Weinstein 1987, Hartofilakidis et al. 2000). The reason for degenerative changes in dysplastic hips is probably mechanical and is possibly related to increased contact stress over time (Weinstein 2001).

In a study by Hartofilakidis et al. (2000), the natural progression of hip disease in the three types of DDH (dysplasia, low dislocation and high dislocation) were studied in 157 patients (202 hips: 102 dysplastic, 42 low dislocation, and 58 high dislocation) who had been untreated before the initial examination. Average length of follow-up was 17 years. In dysplastic hips, the disease remained undiagnosed until the onset of symptoms at an average age of 34.5 years. In patients with a low dislocation, the onset of pain was on average 32.5 years due to progressive degenerative arthritis within the false acetabulum. In patients with a high dislocation, in the presence of a false acetabulum, pain started at an average age of 31.2 years, while in its absence, pain started at an average age of 46.4 years due to muscle fatigue.

### 6.1.3.3 Treatment in childhood

If the diagnosis is missed at birth, the natural progression of dysplasia or dislocation can follow one of four scenarios: the hip can become normal, it can go on to subluxation or partial contact, it can go on to complete dislocation, or it can remain located but retain dysplastic features (Coleman 1968). Because it is not possible to predict the outcome of dysplasia or dislocation detected in the newborn and because the risk of complications of treatment by specialists with a device such as a von Rosen cast or a Pavlik harness is so low, instability of the hip of a newborn has traditionally been treated to ensure the highest rate of normal outcome (Ryöppy 1997). Nowadays, only hips that are found to be dislocated under the Ortolan's test or can be dislocated in the Barlow's test are treated with a cast or harness (personal communication, Helenius 2006). Instability alone is no longer an indication for cast treatment. The purpose of this modern approach is to avoid unnecessary treatments. If treatment with these methods is unsuccessful, skin traction followed by closed reduction, or even open reduction combined with capsulorraphy is required (Ryöppy 1997). If the dislocation is not diagnosed until the child walks, open reduction combined with acetabuloplasty and femoral shortening osteotomy must be performed (Weinstein et al. 2004). The patients who have residual dysplasia after these treatments, and the patients who are diagnosed with DDH at an older age, may require different periacetabular and/or femoral osteotomies to decrease the probability of early degenerative OA of the hip (Weinstein et al. 2004).

### 6.1.3.4 Schanz osteotomy of the femur

Historically, early attempts to reconstruct the hips of adults who had high congenital dislocation were unsuccessful and some authors considered high hip dislocation to be a contra-indication to THA (Charnley and Feagin 1973, Eftekhar 1978). In consequence, palliative operations, such as the Schanz osteotomy were developed (Schanz 1922).

In his original paper, Schanz gave the following reason for his osteotomy: "If a

patient with a unilateral dislocation is asked to take a step forward with her sound leg, she begins to take the step by lifting the heel, bending the knee, and dropping the pelvis on the sound side (the Trendelenburg phenomenon). The pelvis sinks until the lower rim of the pelvic funnel impinges upon the femur. Not until this impingement takes place is the conversion of the pelvis and the femur into a weight-bearing unit complete, and not until then can she raise her toes from the ground and advance the foot" (Schanz 1922). The goal of the Schanz osteotomy is to convert the pelvis and the femur into a weight-bearing unit at the moment the step begins. This can be accomplished by an osteotomy and angulation, in which the proximal femur lies against the oblique wall of the pelvis, while the distal femur lies parallel to the long axis of the body. According to Schanz, osteotomy is carried out at the level of the ischial tuberosity, and an angle opening outward is established between the fragments (Schanz 1922).

Previously, only a few studies have reported the results of the Schanz osteotomy in patients with untreated hip dislocation (Hass 1953, Kivilaakso 1959). Hass (1953) reported the results of Schanz osteotomy in 25 patients, with eight bilateral dislocations. Of these 80% had good, and 20% poor outcomes (Hass 1953).

In Finland, untreated congenital hip dislocation was quite common over 1930's and 1940's. First, owing to the lack of orthopaedic hospitals and second, during and after the 2nd World War treatment of disabled soldiers placed such great demands on limited medical resources, that very frequently patients with hip dislocation did not receive any treatment at all or their treatment was not completed (Kivilaakso 1959). Thus, untreated cases accumulated during those years. Treatment of these neglected cases was almost exclusively carried out by the Orthopaedic Hospital of the Invalid Foundation. Taking these facts into consideration, it is obvious, that the largest published study of Schanz osteotomy in patients with untreated congenital hip dislocation comes from Finland and from the Orthopaedic Hospital of the Invalid Foundation (Kivilaakso 1959). In that study, Kivilaakso published the results of 134 patients (187 hips) with congenital hip dislocation treated with Schanz osteotomy. In that study, all patients diagnosed with congenital hip dislocation were either neglected (92 patients) or unsuccessfully treated (42 patients). Follow-up data on 100 patients (131 hips) were available (range, 2–12 years): unilateral cases showed good or satisfactory results in 72% of the hips, whereas only 6% of bilateral cases achieved good outcomes, and 50% were categorized as poor. Kivilaakso recommended the Schanz osteotomy for young patients (aged 15–17 years) with unilateral congenital hip dislocation. However, for cases of bilateral dislocation, he recommended much more caution should be exercised (Kivilaakso 1959).

#### 6.1.3.5 Classification in adulthood

Several different classifications have been devised to describe the different types of DDH in adults (Eftekhar 1978, Crowe et al. 1979, Hartofilakidis et al. 1996). Traditionally, classifications proposed by Eftekhar (1978) and Crowe (1979) have been used. According to Eftekhar (1978), the height of the dislocation is graded into four stages: stage A (a slightly elongated and dysplastic acetabulum with some deformity of the

head), stage B (an intermediate false acetabulum), stage C (a high false acetabulum), or stage D (an old, unreduced dislocation with the femoral head never having been in contact with the ilium). However, the classifications of Crowe (1979) and Eftekhar (1978) refer to the degree of displacement of the femoral head but do not accurately enough define the acetabular abnormality. The term 'subluxation' is especially misleading because it refers to the degree of displacement of the femoral head but does not define the acetabular abnormality (Crowe et al. 1979). Consequently, a new classification of acetabular deficiencies was developed by Hartofilakidis and co-workers (Hartofilakidis et al. 1996). They suggested the use of the term *congenital hip disease* for the total spectrum of the deformities and its classification into three types on the basis of the relationship between the femoral head and the true or false acetabulum. These types were: dysplasia, low dislocation, and high dislocation. With dysplasia, the femoral head is still contained within the original acetabulum despite some degree of subluxation. With low dislocation, the femoral head articulates with a false acetabulum that partially covers the true acetabulum. Under radiographical examination, there appear to be two overlapping acetabula; the inferior part of the false acetabulum is an osteophyte that begins at the level of the superior rim of the true acetabulum. With high dislocation, the femoral head has migrated superiorly and posteriorly. The true acetabulum is inferior and anterior to the hollow in the iliac wing with which the femoral head articulates, and may have the appearance of a false acetabulum.

### 6.1.3.6 Treatment by total hip arthroplasty

The primary indications for THA in adult patients with DDH are severe pain and/or considerable difficulty with walking and performing daily activities (Charnley and Feagin 1973, Harris et al. 1977, Hess and Umber 1978, Crowe et al. 1979, Paavilainen et al. 1990, Paavilainen et al. 1993, Hartofilakidis et al. 1998, DiFazio et al. 2002, Hartofilakidis and Karachalios 2004, Perka et al. 2004, Chougle et al. 2005). Secondary indications for THA are increased low back pain and/or progressive valgus deformity of the knee (Paavilainen et al. 1990, Paavilainen et al. 1993). National arthroplasty registers' data reveal that 2–9% of THAs have been performed for DDH (Malchau et al. 1993, Havelin et al. 2000, Furnes et al. 2001, AOA 2004). In younger patients, the proportion of patients undergoing THA for DDH has been reported to be higher, the indication for THA being DDH in 8–29% of cases in nation-wide studies (Malchau et al. 1993, Havelin et al. 2000, Furnes et al. 2001, AOA 2004, DHR 2004). However, figures in the Finnish Arthroplasty Register are not reliable because some of the patients registered with the diagnosis of primary OA in fact have mild dysplasia of the hip.

Total hip arthroplasty for high congenital dislocation of the hip presents many technical challenges because of associated anatomical abnormalities (Hartofilakidis et al. 1996, Hartofilakidis and Karachalios 2000). Identification and preparation of the true acetabulum, preparation of the femoral canal, and stable reduction of the components pose several technical problems, especially in patients with high dislocation.

In the treatment of high congenital hip dislocation with THA, several techniques for femoral osteotomy have been published (Yasgur et al. 1997, Hartofilakidis et al. 1998, Chareancholvanich et al. 1999a, Bruce et al. 2000, Perka et al. 2000, Masonis et al. 2003, Hartofilakidis and Karachalios 2004). A shortening osteotomy of the femur and transposition of the greater trochanter has been reported to increase both the abductor lever arm and the functional length of the gluteus medius muscle, creating good abduction strength (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997). However, the long-term efficacy of this procedure has not been studied.

Only Paavilainen and his co-workers have published studies on hip arthroplasty techniques, which can be applied to femora with previous Schanz osteotomies at different levels. Moreover, a shortening osteotomy of the proximal part of the femur with transposition of the greater trochanter should be performed to correct limb-length discrepancy and facilitate reduction of the prosthesis in patients with: hips with a previous unilateral high-seated Schanz osteotomy, or with a bilateral low-seated Schanz osteotomy. Furthermore, adequate limb-lengthening is not possible with the method described above for unilateral cases with a previous low-seated Schanz osteotomy. Instead, the authors recommended metaphyseal segmental shortening with angular correction to allow reduction and the proper lengthening of the limb. With segmental metaphyseal osteotomy, a step-method is used to stabilize the osteotomy against rotation. However, a segmental metaphyseal osteotomy is a laborious and time-consuming procedure. Moreover, the risk of fracturing the proximal fragment is considerable, and the magnitude of functional lengthening of the leg is limited to only three centimeters. (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997)

Because of technical difficulties related to THA in patients with high congenital dislocation, complication rate of this procedure has been reported to be substantially higher than that of THA in hips with normal anatomy (Woolson and Harris 1983, Paavilainen et al. 1990, Paavilainen et al. 1993, Jasty et al. 1995, Paavilainen 1997, Hartofilakidis et al. 1998, Anderson and Harris 1999, Hartofilakidis and Karachalios 2004, Perka et al. 2004, Klapach et al. 2005, Lai et al. 2005). The risk of neurological complications is especially high (Woolson and Harris 1983, Paavilainen et al. 1990, Paavilainen et al. 1993, Jasty et al. 1995, Paavilainen 1997, Hartofilakidis et al. 1998, Anderson and Harris 1999, Hartofilakidis and Karachalios 2004, Perka et al. 2004, Klapach et al. 2005, Lai et al. 2005) and with subtrochanteric osteotomies, the risk of fracturing the proximal part of the femur is also increased (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997, Bruce et al. 2000, Perka et al. 2000, Sener et al. 2002).

## 6.2 Arthroplasty registers

A national joint replacement register was first set up in Sweden in 1979 (Ahnfelt et al. 1990). Similar registers were then established in Finland in 1980 (Paavolainen et al. 1991), Norway in 1987 (Havelin et al. 1993), Denmark in 1995 (Lucht 2000) and in Australia in 2000 (AOA 2004).

The most important purpose of the registers is to identify inferior implants and methods used in THA as soon as possible. In Norway, poor results regarding some inferior THRs and a cement brand used

in THA has been detected after only three years of use (Havelin et al. 1995b, Havelin et al. 1995a, Havelin et al. 1995c, Furnes et al. 1997). Naturally, only very inferior implants and methods can be detected that early. Larger numbers of patients and longer follow-ups enable smaller differences between implants and methods to be detected and assessed.

With the aid of arthroplasty registers, epidemiological trends of THA (Paavolainen et al. 1991, Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002) and mortality associated with THA (Lie et al. 2000, Paavolainen et al. 2002) can also be analyzed on a nation-wide level. In addition, other issues such as cancer risk associated with THA can be analyzed by matching data from arthroplasty and cancer registers (Visuri et al. 1996). The future need for THA can also be predicted using national registry data (Ostendorf et al. 2002).

Results from observational, register-based studies are often regarded as being less conclusive than those from comparable randomized trials. However, recent studies have indicated that properly conducted large prospective observational reviews may give results which are similar to those of large randomized trials (Benson and Hartz 2000, Concato et al. 2000). Furthermore, patients who participate in randomized studies are frequently atypical, and specific exclusion criteria may be so restrictive that only a small proportion of patients treated in regular clinical practice are represented. Therefore, it has been suggested, that the effectiveness of a widely used surgical techniques, such as THA, would be better evaluated by observational approaches, such as in a register-based study, rather than in randomized studies (Herberts and Malchau 2000).

## 6.3 Causal mechanisms of failure of total hip replacements

### 6.3.1 Aseptic loosening

Loosening of the components is the most common reason for revision of THA both in younger and in older patients (Paavolainen et al. 1991, Havelin et al. 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, NAR 2005, SOS 2005). The process of hip implant loosening is often multifactorial. Primary stability of the implant is crucial for long-term success (Mjoberg 1994). Adequate primary stability is acquired for cementless implants to obtain osseointegration (Pilliar et al. 1986). With cemented implants, a sufficient bone-cement interface is required to gain adequate primary stability and long-lasting fixation (Havelin et al. 1995b). Adequate acetabular and femoral fixation can be achieved both with bone cement (Charnley 1979, Maloney et al. 1989, Malcolm 1993) and with various cementless surfaces (Bauer et al. 1991, Bauer et al. 1993, Engh et al. 1995, Tonino et al. 1999, Bohm et al. 2001, Coathup et al. 2001, Tonino et al. 2001). Another important factor of implant loosening is wear debris induced osteolysis. It has been established that the local reaction to particulate wear debris initiates the formation of a granulomatous tissue that ultimately invades the bone-implant interface and results in aseptic loosening (Schmalzried et al. 1992b). Cement mantle defects (Kawate et al. 1998), non-circumferential porous coatings (Bobyn et al. 1995), and screw holes (Sumner et al. 1993) of the acetabular component can serve as preferential access pathways for the progression of this granulomatous process leading to implant loosening.

## 6.3.2 Wear and osteolysis

### 6.3.2.1 Wear

Wear arises from the breaking away of material, which occurs as a result of friction and motion between two surfaces under load. Wear of hip replacement articulations depends on several factors, such as the surface finish, the material hardness, the type of lubricant, the femoral head diameter, the joint pressure and the number of gait or motion cycles (Ritter et al. 1996, Schmalzried et al. 2000). Many types of polymers have been used as bearing surfaces in THA; all but conventional polyethylene (PE) based designs have been abandoned due to excessive wear (Charnley 1979, Havelin et al. 1986). PE that has been modified into ultra-high molecular weight polyethylene (UHMWPE) has become the most common type of articular surface on the acetabular component. Mean annual wear rates of ca. 0.1–0.2 mm for UHMWPE have been commonly reported (Charnley and Halley 1975, Livermore et al. 1990, Sochart 1999, Kim et al. 2003b). In practice, this leads to the release of enormous numbers of submicron particles at the joint (McKellop et al. 1995). Substantial reductions in volumetric wear on first- and second-generation metal-on-metal implants have been shown in comparison with conventional metal-on-UHMWPE articulation surface couples (McKellop et al. 1996, Schmidt et al. 1996). Retrieval studies on ceramic bearing surfaces have generally concluded that these materials also generate a markedly lower volume of debris in comparison with conventional metal-on-UHMWPE couples (Dorlot et al. 1989, Mittelmeier and Heisel 1992, Boehler et al. 1994). The most modern form of PE, i.e. highly cross-linked polyethylene, has been more resistant to abrasives in hip simulator studies (McKellop et al. 1999, Muratoglu et al. 2001a, Muratoglu et al. 2001b). In a recent clinical study with a minimum follow-up of five years, the annual linear wear rate of the highly cross-linked polyethylene was 45% of that seen with the conventional PE liner (Dorr et al. 2005).

The causes of PE wear can be divided into endogenous and exogenous factors (Lewis 1997). Factors, which are related to the material, are termed endogenous and other factors exogenous. The quality of PE is influenced by the manufacturing process (Bankston et al. 1995, Tanner et al. 1995, Lewis 1997) and the sterilizing method (Premnath et al. 1996, Kurtz et al. 1999a, Ries et al. 2001). Poor design of the acetabular component can lead to excessively thin PE liners, which lead to increased stress and wear (Bartel et al. 1986, Jasty et al. 1997, Lee et al. 1999). Modularity of the acetabular component leads to varying amounts of wear on the attachment surface (backside wear), as there is always some motion between the modular liner and the metal shell (Williams et al. 1997, Fehring et al. 1999); non-conformity between the liner and the metal shell increases this motion and results in backside wear (Kurtz et al. 1998). The presence of screw holes does not substantially increase abrasive backside wear when compared with the effects of backside non-conformity (Kurtz et al. 1999b). However, screw holes may facilitate transport of particles to the bone-implant interface (Huk et al. 1994). The volumetric wear is directly linked to the size of the femoral head; i.e. smaller heads produce less wear debris (Livermore et al. 1990, Kesteris et al. 1996, Hall et al. 1998). Cementless metal-

backed liners have had higher wear rates than cemented all-polyethylene cups in retrieval studies (Sychterz et al. 1996, Jasty et al. 1997). In one clinical study, lateralization of the femoral component more closely restored preoperative hip biomechanics and significantly decreased polyethylene wear (Sakalkale et al. 2001). In cementless THAs, increased abduction angle of the cup seems to increase PE wear (Kennedy et al. 1998). Looseness of the artificial hip joint may also increase wear through telescopic movement between the bearings (Lombardi et al. 2000). Wear has been shown to be a function of use, not of time; in a clinical study patient activity, assessed by a pedometer, a step activity monitor and by a simple visual analog scale, strongly correlated to wear (Schmalzried et al. 2000). This may partly explain the higher wear rates observed in younger patients (Shih et al. 1997) and in males (Schmalzried et al. 2000). The effect of male gender on wear may also be attributable to differences in behaviour, i.e. the types and patterns of activity.

#### 6.3.2.2 Osteolysis

Periprosthetic osteolysis is bone resorption, which occurs in association with a foreign-body such as in response to particulate debris from a prosthetic joint (Amstutz et al. 1992). Histological evaluations of tissues around failed primary arthroplasties have revealed metal, cement, and PE particles (Nasser et al. 1990, Buly et al. 1992, Schmalzried et al. 1992a). It is generally believed that PE wear debris is the main cause of osteolysis (Hirakawa et al. 1996b).

Wear-mediated periprosthetic osteolysis is unlikely to be caused solely by one particular cell type or particulate species, rather it is the cumulative consequence of a number of biological reactions. Recent findings suggest three novel mechanisms of particle bioreactivity that may contribute to osteolysis (Santavirta et al. 1998, Wang et al. 2004, Konttinen et al. 2005): (1) exacerbated inflammation caused by elevated reactive oxygen species production resulting from activated macrophages and osteoclasts, (2) impaired periprosthetic bone formation secondary to disrupted osteogenesis, and (3) compromised bone regeneration resulting from increased cytotoxic response of mesenchymal osteoprogenitor cells.

Large numbers of particles have been recognized in periprosthetic tissues, with the highest concentration of particles in the proximal femoral interfacial membranes. Lesser concentrations of particles were seen in the acetabular interfacial membranes and the joint pseudocapsule (Hirakawa et al. 1996a, Hirakawa et al. 1996b, Hirakawa et al. 1997). These findings are are consistent with the concept of the effective joint space in which joint fluid, laden with wear debris primarily generated at the articular surfaces has widespread access to the periprosthetic tissues (Schmalzried et al. 1992b).

Although PE is the dominant particle material in most retrieval studies, this is not the case when ceramic-on-ceramic or metal-on-metal wear couples are involved. Ceramic-on-ceramic bearings have been shown to yield particles that, though typically less in number than PE particles, are comparable in size (Yoon et al. 1998) and bioactivity (Catelas et al. 1998, Catelas et al. 1999). In contrast, tissues retrieved from patients with metal-on-metal bearings have particles that are an order of magnitude smaller than either PE or ceramic particles (Doorn et al. 1998). Even though tissues as-

sociated with metal-on-metal bearings may have a milder inflammatory reaction overall (Doorn et al. 1996), there is at least one report of early osteolysis following second-generation metal-on-metal hip replacement indicative of a delayed-type hypersensitivity response (Park et al. 2005).

It has been suggested that there is a critical wear rate threshold above which the risk of osteolysis is disproportionately increased; this threshold is 0.1–0.2 mm/yr (Sochart 1999, Dowd et al. 2000, Orishimo et al. 2003). On the other hand, Wilkinson and co-workers (2005) recently found, that the incidence of osteolysis increased in a linear manner with each quintile increase in wear rate throughout the range 0.01–0.54 mm/year. They suggested that the association of osteolysis with PE wear rate represents a continuous positive use–response relationship, a finding which does not support the concept of a discrete critical wear rate threshold.

The clinical consequences of wear debris cover a broad spectrum from a radiolucence to massive osteolysis and implant failure. Osteolysis is a major complication. It is often asymptomatic and therefore continuous radiographical follow-up is necessary (Harris 2001) to enable revision to be performed before severe bone destruction has occurred. The clinical importance of this phenomenon in young patients has been reported by Sochart (1999): in a study on 235 Charnley low-friction arthroplasties (Charnley LFAs) in patients aged less than 40 years the author found, that there was significantly less osteolysis in patients with mean annual wear rate of <0.1 mm than in patients who had a mean wear rate of >0.25 mm /yr (9 % vs. 35 %). What is more, the 20 year survival rates were 92 % for the low-wear group but only 12 % for the high-wear group, respectively.

## 6.4 Results of THA in young patients

Results of modern THA are excellent in older (>60 years of age) patients; >95% 10 year survival rates have been reported from several sources, even at a nation-wide level (Havelin et al. 2000, Herberts and Malchau 2000, Furnes et al. 2001, Malchau et al. 2002, AOA 2004, DHR 2004, NAR 2005, SOS 2005). Good long-term results have also been reported in young patients, but those studies either have originated from specialized centers (Boeree and Bannister 1993, Joshi et al. 1993, Emery et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Fye et al. 1998, Sochart and Porter 1998) or they report an individual surgeon's results (Keener et al. 2003, Kim et al. 2003b). Therefore, caution is needed for interpreting these results. However, in register-based studies, the outcome of THA has been poorer in younger than in older patients (Havelin et al. 2000, Malchau et al. 2002, DHR 2004). As early as 1979 the pioneer of modern THA, Sir John Charnley, stated: "The challenge comes when patients between 45 and 50 years of age are to be considered for the operation, because then every advance in technical detail must be used if there is to be a reasonable chance of 20 and more years of trouble-free activity" [sic] (Charnley 1979). Nowadays almost three decades later the ultimate challenge for the orthopaedic surgeon performing THA is still the younger patients, whose life expectancy is well into the eighth decade, and who put a great demand on their artificial hip joints.

Relatively few patients who are younger than 55 years old need THA, and operations on large numbers of such patients have, mostly been performed in specialized centers. Many of the previous studies have limitations including an insufficient number of patients for reliable statistical analysis (Collis 1991, Barrack et al. 1992, Boeree and Bannister 1993, Ballard et al. 1994, Emery et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1998, Keener et al. 2003), different THR designs have been used in a single series (Collis 1991, Barrack et al. 1992, Boeree and Bannister 1993, Ballard et al. 1994), or they describe the results of THA in the hands of single surgeons in specialized centers (Barrack et al. 1992, Wroblewski and Siney 1992, Ballard et al. 1994, Keener et al. 2003, Kim et al. 2003b, Kim et al. 2004). It has also been reported, that the outcome of THA in younger patients may depend on the pathology of the hip joint (Joshi et al. 1993, Sochart and Porter 1997a). Despite this young patients with different hip diseases are included in most studies in an attempt to increase the total number of patients (Halley and Wroblewski 1986, Barrack et al. 1992, Wroblewski and Siney 1992, Boeree and Bannister 1993, Ballard et al. 1994, Devitt et al. 1997, Emery et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1998, Keener et al. 2003). The results of different diagnostic subgroups are reported separately in only a few studies (Joshi et al. 1993, Sochart and Porter 1997b, Sochart and Porter 1997a).

### 6.4.1 Clinical evaluation

Several different scoring systems have been used in evaluating the results of THA (D'Aubigne and Postel 1954, Harris 1969, Kavanagh and Fitzgerald 1985). They typically describe pain, motion and walking ability of the patients who have undergone a THA. The most commonly used scoring system is the HHS, which was introduced in 1969 and included both daily living activities and the type and extent of deformity (Harris 1969). This scoring system had originally been designed to evaluate the outcome after an acetabular fracture. Since then the HHS has been widely used to evaluate the clinical results after a THA. Specific pain drawings and visual analogue scales can also be used in describing pain (Huskisson 1974).

Performance of the abductors determines hip function (Inman 1947). Thus, it is essential to evaluate the abduction function of the hip joint after THA particularly in patients who have a severe limp before the operation; e.g. patients with a high congenital hip dislocation (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997, Hartofilakidis et al. 1998, Hartofilakidis et al. 2000). The abduction strength of the hip can be measured by several methods. The range of active abduction can be assessed with the patient lying in the lateral decubitus position and elevating the affected extremity against gravity, with the knee in extension. This method has been reported to be sensitive in evaluating the hip abduction function. Another method is to ask the patient to elevate the affected extremity against resistance by the physician's hand, and the strength of abduction of the hip is graded according to the standard Medical Research Council scale (MRC grades 0 through 5) (Seddon 1954). The Trendelenburg test is also a widely accepted screening method to measure abduction function.

When the results of a THA series are evaluated, it is essential that the observer is

independent, i.e. the surgeon must not be involved. The clinical outcome parameters of THA are blunt instruments to detect implant failures, as complications from the implant (e.g. wear and osteolysis) will rarely cause any pain in the early phase. Thus, long-term radiographical examination follow-up is always needed to detect clinical failures of THA.

Various statistical methods are used to calculate the survival rates of implants. Survival rate analyses of different hip implants are usually determined by the Kaplan-Meier method (Kaplan and Meier 1958) or the Cox regression analysis (Cox 1972). The Kaplan-Meier survival analysis was originally developed for other research areas but it has also become very commonly used for evaluating the survival of THAs. The definition of a failure is a very important issue, as the definition per se may have a marked effect on the results. Failure of a THA may be defined in different ways: the decision to perform a revision operation, an actual revision operation, or early signs of loosening as determined by radiography can all be defined as a failure. Indications and resources to perform revisions vary, as do the definitions of loosening under radiographical examination. Thus, the end-point criteria of failure are critical in survival analyses. In addition, the number of patients at risk decreases with time in survival analyses. Thus, survival rates should always be presented with confidence intervals. Furthermore, when survival curves are calculated, they should not be presented beyond a point, where less than 15–20 patients are still at risk. Moreover, the 95% confidence interval of the estimated survival curve should always be presented for the last follow-up period for which the survival curve is being drawn (Dorey 2004). When survival rates of different implant design concepts or designs are compared, one should either select subgroups of patients who are homogeneous as regards age, gender and diagnosis, or adjust for these and other confounding factors using a Cox regression model (Havelin et al. 2000, Furnes et al. 2001).

Observational studies based on data obtained from national arthroplasty registers provide valuable insight into the use of the THA procedure in a certain patient-group. Such an approach has an advantage over clinical studies from single centres in that the number of arthroplasties studied is substantially larger. The results can also be compared between other Nordic arthroplasty registers, which gives a broad perspective on the results for both single implants and the methods applied in THA (Havelin et al. 2000, Puolakka et al. 2001b, Malchau et al. 2002). In Sweden, results of THA have improved due to long-term registration of THAs (Herberts and Malchau 2000). Subjective outcome measurements, e.g. HHS or disease-specific quality of life measurements, cannot usually be reported in register-based studies. Moreover, it is not possible to conduct radiographical analyses in register-based analyses involving thousands of patients. Thus, only revision operations can be used as the end point for failure in register-based studies.

There is usually a long time lag between implantation and failure of a THA. In practice, a large number of patients must be treated with a new THA or surgical technique, before the true efficacy of the procedure can be evaluated. It has been suggested, that new THA design concepts should first be tested with radiostereometric analysis (RSA) in a small group of patients and then

in multi-center prospective clinical studies, before they are widely introduced in hospitals (Kärrholm 2003). Thus, the number of patients exposed to the potential hazards of a new technique can be minimized.

### 6.4.2 Radiographical evaluation

Certain standardized methods are commonly used in radiographical evaluation of hips after THA. An anteroposterior radiograph is usually taken with the patient bearing weight and the feet parallel with each other (Turula et al. 1985). To obtain consistent and comparable radiographs, the x-ray beam should be centered on the symphysis pubis. The film-focus distance and the exposure rate should also be as highly standardized as possible to allow comparisons between examinations done at increasing time intervals after implantation. The lateral frog-leg radiograph is usually taken with the patient supine. Uncemented femoral and acetabular components are commonly assessed by the method described by Johnston et al. (1990). The stability of an uncemented femoral component is classified as bone-ingrown, fibrous stable, or unstable according to the system of Engh et al. (1987). The femoral stem interface is analyzed in seven regions of the frontal plane and seven regions of the sagittal plane (Gruen et al. 1979). On the acetabular side, radiolucent lines with a width of >1 mm at the component-bone interface are recorded for the three zones defined by DeLee and Charnley (1976). Osteolytic lesions are similarly counted, classified and documented by size and location (DeLee and Charnley 1976, Gruen et al. 1979). It is generally accepted that loosening of the femoral component is defined as a change in position of >3 mm, and loosening of the acetabular component is defined as a change in alignment of >2° or a change in position of 2 mm. Heterotopic ossification is generally classified into four grades (Brooker et al. 1973).

The extent of linear wear of the PE liner can be estimated from plain radiographs. Several different methods that evaluate wear have been published (Charnley and Cupic 1973, Charnley and Halley 1975, Russe 1988, Livermore et al. 1990, Devane et al. 1995a, Devane et al. 1995b, Krismer et al. 1995). The classic uni-radiographical technique of Charnley and Cupic measures only vertical linear wear. This is done by measuring the width of the narrowest part of the socket in the weight-bearing area and the width of the widest part in the non-weight-bearing area and the difference between them is halved (Charnley and Cupic 1973). In 1975, Charnley and Halley introduced a duoradiographical comparative method: the most recent radiographs are compared to early postoperative radiographs, in which the distance between a radiographical marker and the outline of the femoral head is assessed (Charnley and Halley 1975). In a method described by Livermore in 1990, the thinnest part of the PE should be measured and compared with the postoperative radiograph (Livermore et al. 1990). Both of these duoradiographical methods use the opening face of the socket as a reference and wear is calculated as the change in position of the femoral head relative to this acetabular face reference line. All these methods have been found to correlate with direct assessment of the internal deformity of 28 retrieved sockets (Ohlin and Selvik 1993). However, PE wear in these two-dimensional techniques may be underestimated, as multiple wear factors are actually in-

volved (Yamaguchi et al. 1997). Since this method was first described, more-accurate three-dimensional computerized methods have been developed (Devane et al. 1995a, Devane et al. 1995b, Ilchmann 1997, Shih et al. 1997, Chen and Shih-Shyn Wu 2002). It should be noted that two- and three-dimensional measurements have been found to give more or less equal estimates in 95% of the cases (Sychterz et al. 1999). The most accurate method of measuring both migration and wear is radiostereometric analysis (RSA) (Aronson et al. 1974), which can only be used in prospective studies, as tantalum markers must be implanted intraoperatively.

## 6.4.3 Special aspects regarding THA in young patients

### 6.4.3.1 Reasons for failure of THA in young patients

In general, the most common reason for revision of THA is aseptic loosening, which accounts for 50–79 % of all revisions in nationwide studies (Malchau et al. 1993, Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, NAR 2005, SOS 2005). This is followed by prosthesis dislocation (6–15%), deep infection (5–11%), periprosthetic fracture (4–8%), technical errors (2–6%), implant failure (2–5%), osteolysis without loosening (2–10%), exchange of worn liner (1–5%), and pain (0–7%) (Malchau et al. 1993, Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, NAR 2005, SOS 2005).

Most of the early revisions (<1 year after THA) are performed because of dislocation and deep infection (AOA 2004, SOS 2005), whereas later on loosening is the main reason for revision (Malchau et al. 1993, Havelin et al. 2000, Lucht 2000, Puolakka et al. 2001b, Malchau et al. 2002, AOA 2004, DHR 2004, NAR 2005, SOS 2005). In Australia 33% of revisions performed during the first postoperative year were due to dislocation (AOA 2004). Data from the Swedish arthroplasty register reveal that during the first three postoperative years 19% of revisions were performed for deep infection and 17% for dislocation. At the same time, over 80% of revisions performed more than four years after primary THA were due to aseptic loosening (SOS 2005). However, risk of revision secondary to deep infection as a whole has decreased both in Sweden and in Norway. This can be attributed to the wide-spread use of systemic antibiotics combined with antibiotic-containing bone cement (Espehaug et al. 1997, Herberts and Malchau 2000). In Sweden, a trend towards an increasing risk of revision due to dislocation has been obtained recently (SOS 2005). In Norway, an increase in the incidence of revisions secondary to osteolysis and wear has been observed for the 1996–2004 period (NAR 2005).

Population-based data giving reasons for THA revisions in younger patients have not been published. However, reasons for revision obtained from clinical studies from single centers in younger and in older patients have been similar (Barrack et al. 1992, Wroblewski and Siney 1992, Boeree and Bannister 1993, Joshi et al. 1993, Ballard et al. 1994, Neumann et al. 1996, Berger et al. 1997, Devitt et al. 1997, Emery et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Fye et al. 1998, Sochart and Porter 1998, McLaughlin

and Lee 2000, Smith et al. 2000, Chiu et al. 2001a, Chiu et al. 2001b, Duffy et al. 2001, Aldinger et al. 2003, Capello et al. 2003, Keener et al. 2003, Kim et al. 2003a, Kim et al. 2003b, Kim et al. 2004, Lyback et al. 2004).

The probability of revision of the acetabular component in young patients has been consistently higher than that of the femoral component, both with cemented (Barrack et al. 1992, Wroblewski and Siney 1992, Boeree and Bannister 1993, Joshi et al. 1993, Ballard et al. 1994, Neumann et al. 1996, Emery et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Sochart and Porter 1998, Smith et al. 2000, Chiu et al. 2001a, Keener et al. 2003) and uncemented THAs (Berger et al. 1997, Fye et al. 1998, McLaughlin and Lee 2000, Chiu et al. 2001b, Duffy et al. 2001, Aldinger et al. 2003, Capello et al. 2003, Kim et al. 2003a, Kim et al. 2003b, Kim et al. 2004, Lyback et al. 2004). There were only a few exceptions to this finding (Devitt et al. 1997, Kobayashi et al. 1997).

### 6.4.3.2 Results of different THA fixation concepts in young patients

#### 6.4.3.2.1 Cemented THA

The long-term results of cemented THA in younger patients are dominated by a few implants and methods (Table 2). First, regarding studies on long-term results of cemented THA in younger patients, Charnley LFA has been used either solely (Wroblewski and Siney 1992, Joshi et al. 1993, Devitt et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997a, Sochart and Porter 1998, Keener et al. 2003) or at least in a clear majority of the cases (Collis 1991, Barrack et al. 1992, Boeree and Bannister 1993, Ballard et al. 1994). There was only one exception to this reported in the literature (Emery et al. 1997). Second, long-term results of modern second-generation cementing techniques have only been reported in three studies (Ballard et al. 1994, Emery et al. 1997, Kobayashi et al. 1997) and results of third-generation cementing techniques in younger patients have not been published so far. 10 year survival rates ranging from 79 to 93% have been reported for the whole THA, 92–97% for the femoral component and 83–98% for the acetabular component (Collis 1991, Barrack et al. 1992, Wroblewski and Siney 1992, Boeree and Bannister 1993, Joshi et al. 1993, Ballard et al. 1994, Devitt et al. 1997, Emery et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Sochart and Porter 1998, Keener et al. 2003). At 20 years, survival rate range of cemented THAs was 67– 75% (Joshi et al. 1993, Devitt et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Sochart and Porter 1998, Keener et al. 2003); that of femoral components was 76–86% and that of acetabular components 70–84%. However, a study of young (<40 years old) Chinese patients, by Chiu and colleagues (2001a) found a 27% survival rate for the acetabular component of the Charnley LFA at 15 years. What is more, survival rates of cemented THA clearly declined in those studies in which radiographic loosening of the THR were taken into account in survival analyses, (Ballard et al. 1994, Kobayashi et al. 1997, Chiu et al. 2001a, Keener et al. 2003).

Reported mean annual rates of linear wear for cemented THA have ranged from 0.08 to 0.14 mm (Ballard et al. 1994, Devitt et al. 1997, Emery et al. 1997, Kobayashi et

al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Sochart and Porter 1998, Keener et al. 2003). Substantially higher wear rates have been found in revised THAs compared with unrevised THAs (Sochart and Porter 1997b, Sochart and Porter 1997a, Sochart 1999). In addition, varying wear rates have been reported for different hip diseases (Sochart and Porter 1997a, Sochart and Porter 1998). There are two studies in which wear rates of THAs were higher in patients with degenerative OA compared with patients with RA (Sochart and Porter 1997a, Sochart and Porter 1998). Although the incidence of osteolysis in cemented THAs has been reported to be lower than in uncemented THAs in younger patients (Harris and Maloney 1989, Schmalzried and Harris 1993, Ballard et al. 1994, Berger et al. 1997, Devitt et al. 1997, Emery et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Fye et al. 1998, Sochart and Porter 1998, McLaughlin and Lee 2000, Chiu et al. 2001b, Duffy et al. 2001, Aldinger et al. 2003, Capello et al. 2003, Keener et al. 2003, Kim et al. 2003a, Kim et al. 2003b, Kim et al. 2004, Lyback et al. 2004), Smith and co-workers reported a 51% incidence of acetabular osteolysis and a 32% incidence of femoral osteolysis in young patients after a cemented THA at a mean follow-up of 18 years (Smith et al. 2000).

**Table 2.** Long-term results of cemented THA in young patients.

| | Hips | THR design(s) | Age (mean) | FU | Wear [a] | Cementing method [b] | 10-year survival rate (%) | | | 20-year survival rate (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cup | Stem | THR | Cup | Stem | THR |
| Collis 1991 (IS) | 44 | Charnley / T28 Harris | <50 (41) | 13 | - | 1 | | | 83 | | | |
| Barrack et al. 1992 (IS) | 50 | CAD / HD-2 Harris / Calcar rep. | <50 (41) | 12 | - | 2 | | | 88 | | | |
| Boeree and Bannister 1993 | 46 | 29 Charnley LFA, 17 Howse | <50 (38) | 12 | - | 1 | - | - | 90 | - | - | - |
| Joshi et al. 1993 | 166 | Charnley LFA | <40 (32) | 16 | - | 1 | 96 | 97 | 93 | 84 | 86 | 75 |
| Ballard et al. 1994 (IS) | 42 | 30 Charnley LFA, 13 Iowa / Sarmiento | <50 (41) | 11 | 0.08 | 2 | 83 [c] | 95 [c] | 79 | - | - | - |
| Neumann et al. 1996 | 52 | Charnley LFA | ≤55 (51) | 17 | - | 1 | - | - | - | - | - | 88 |
| Devitt et al. 1997 | 132 | Charnley LFA | <50 (42) | 18 | 0.14 | 1 | >90 [d] | >90 [d] | <90 [d] | 84 | 79 | 75 |
| Emery et al. 1997 | 57 | Stanmore | <50 (41) | 13 | 0.12 [e] | 1 / 2 | - | - | 90 | - | - | - |
| Kobayashi et al. 1997 | 55 | Charnley LFA | ≤50 (37) | 14 | 0.09 | 1 / 2 | 98 | 95 | - | - | - | - |
| Sochart and Porter 1997a | 226 | Charnley LFA | <40 (32) | 20 | 0.11 | 1 | 93 | 95 | 91 | 71 | 82 | 67 |
| Sochart and Porter 1997b | 43 | Charnley LFA | <40 (29) | 23 | 0.12 | 1 | - | - | 91 | 73 | 91 | 73 |
| Sochart and Porter 1998 | 83 | Charnley LFA | <30 (25) | 20 | 0.12 | 1 | 92 | 93 | 89 | 70 | 76 | <70 [d] |
| Smith et al. 2000 (IS) | 47 | NA | ≤50 (41) | 18 | 0.14 | 2 | >90 [d] | >95 [d] | - | - | - | - |
| Keener et al. 2003 (IS) | 93 | Charnley LFA | <50 (42) | 20 | 0.09 | 1 | - | - | 90 [d] | 76 [c] | 94 [c] | 69 |

[a] Mean annual rate of linear wear.
[b] Cementing method: 1 = first-generation technique, 2 = second-generation technique
[c] Aseptic loosening of the component as the end point.
[d] Estimated from a survival curve.
[e] Calculated from data in the original paper.
LFA = Low-friction arthroplasty. FU = mean follow-up time in years. IS = individual surgeon's results. NA = not available

#### 6.4.3.2.2 Uncemented THA

Results of uncemented THA are shown in table 3. First reports on cemented THAs revealed high failure rates in young patients (Chandler et al. 1981, Sharp and Porter 1985, White 1988, Dorr et al. 1990). Later on, improved results were obtained with the use of Charnley LFA (Joshi et al. 1993, Neumann et al. 1996, Devitt et al. 1997, Callaghan et al. 1998), or with improved cementing techniques used on the femoral side (Barrack et al. 1992, Ballard et al. 1994, Wroblewski et al. 1998). However, the problem of acetabular loosening of cemented cups was not substantially alleviated by contemporary cementing techniques such as pressurization and centrifugation (Wroblewski 1986, Barrack et al. 1992, Schulte et al. 1993, Sullivan et al. 1994). Harris and co-workers (1976) reported extensive non-linear osteolysis in the proximal femur after cemented THA. This phenomenon was believed to be due to 'cement disease', and poor results of cemented THAs were considered to be associated with the use of bone cement. Thus, cementless THAs were developed in a search for an optimal solution for the young patients, and they gave good short-term results (D'Antonio et al. 1992, Schmalzried and Harris 1992, Heekin et al. 1993).

Regarding the long-term results of uncemented THA, none of the published studies reported 15 or 20 year survival rates (Berger et al. 1997, Fye et al. 1998, McLaughlin and Lee 2000, Chiu et al. 2001b, Duffy et al. 2001, Aldinger et al. 2003, Capello et al. 2003, Kim et al. 2003a, Kim et al. 2003b, Kim et al. 2004, Lyback et al. 2004): 10 year survival rates of uncemented THAs have ranged from 67 to 100 %. However, durability of the femoral component has been superior to that of the acetabular component in all studies (Berger et al. 1997, Fye et al. 1998, McLaughlin and Lee 2000, Chiu et al. 2001b, Duffy et al. 2001, Aldinger et al. 2003, Capello et al. 2003, Kim et al. 2003a, Kim et al. 2003b, Kim et al. 2004, Lyback et al. 2004). Furthermore, 10 year survival rates ranging from 85 to 100% and from 49 to 100% were reported for uncemented stems and cups, respectively. What is more, wear rates and incidence of periprosthetic osteolysis have been higher in uncemented than in cemented THAs in younger patients (Ballard et al. 1994, Berger et al. 1997, Devitt et al. 1997, Emery et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Fye et al. 1998, Sochart and Porter 1998, McLaughlin and Lee 2000, Chiu et al. 2001b, Duffy et al. 2001, Aldinger et al. 2003, Capello et al. 2003, Keener et al. 2003, Kim et al. 2003a, Kim et al. 2003b, Kim et al. 2004, Lyback et al. 2004).

**Table 3.** Long-term results of uncemented THA in young patients.

| | | THR design [a] | | | | | Osteolysis (%) | 10-year survival rates (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Hips | Stem | Cup | Mean age | FU | Wear [b] | | Cup | Stem | THR |
| Berger et al. 1997 | 72 | Various | HG I (1) | <50 (37) | 8.8 | 0.16 | 7 (a) | 88 | - | - |
| Fye et al. 1998 | 72 | Various | Various | <50 (37) | 7.0 | - | - | - | - | 97 [c] |
| McLaughlin and Lee 2000 (IS) | 100 | Taperloc (2) | T-Tap (1) | ≤50 (37) | 10.2 | - | 9/25 | - | 98 | - |
| Chiu et al. 2001b | 61 | AML (1)/PCA (1) | AML (1) / PCA (1) | ≤40 (33) | 7.6 | 0.18 / 0.20[e] | 56 (y) | - | - | 67 |
| Duffy et al. 2001 | 82 | Various (1) [f] | Various (1) [f] | <40 (32) | 10 | - | - | 81 | 85 | 78 |
| Aldinger et al. 2003 | 154 | CLS (2) | Various (1) | <55 (47) | 12 | - | 17 (a) | 81 | 97 | - |
| Capello et al. 2003 | 111 | Omnifit HA (2) | Omnifit HA / porous (2) | <50 (39) | 11.3 | - | 47 (f) | <80[g] | >95[g] | - |
| Kim et al. 2003b (IS) | 118 | Profile (2) | Duraloc 100 / 1200 (2) | <50 (47) | 9.8 | 0.12 | 9/12 | 99 | 99 | 99 |
| Kim et al. 2003a (IS) | 100 | IPS[h] (2) | Duraloc 100 / 1200 (2) | <62 (45) | 6.6. | 0.18 / 0.21[h] | 0 (a/f) | 100/98[h] | 100 | - |
| Lyback et al. 2004 | 77 | Bi-Metric (2) | T-Tap (1) / Romanus (1) | ≤60 (28) | 9.7 | - | - | 49/78 [k] | 97 | 70 |

[a] Implant generation in parentheses
[b] Mean annual rate of linear wear.
[c] Survival rate at 11 years.
[e] PCA / AML
[f] Various 1st generation designs: PCA, Harris-Galante I, and Osteonics.
[g] Estimated from a survival curve.
[h] All stems were proximally porous-coated, and 50% of them had an additional HA-coating. Wear rates and cup survival: HA / non-HA-coated groups.
[i] Metal-on-metal articulation.
[j] Aseptic loosening as the end point.
[k] T-Tap / Romanus
FU = Mean follow-up time in years. HG = Harris-Galante.

#### 6.4.3.2.3 Hybrid THA

As the loosening of the acetabular component of the cemented THA continued to be a problem in young patients, hybrid THR consisting of a cementless acetabular component and a cemented femoral component was developed in an effort to maximize the durability of fixation and the longevity of the prosthesis (Harris and Maloney 1989, Schmalzried and Harris 1993). The so called "reverse hybrid" fixation concept consists of a cemented acetabular component and an uncemented femoral component (Alho et al. 2000). Reverse hybrid THAs have been implanted into patients in Finland and in Norway (Nevalainen 2004, NAR 2005).

Long-term results of THA in young patients using a hybrid THA have only been reported in one single study (Kim et al. 2002). In that study, Kim and co-workers reported a 98% survival rate for a hybrid THA at 10 years with any revision as the end point. Using third-generation cementing techniques, they had no revisions for aseptic loosening of the cemented stem. None of the modern third-generation acetabular components were revised for aseptic loosening either. The authors reported a 0.096 mm annual linear wear rate, and a 9% incidence of osteolysis in the calcar

femorale. No osteolysis was observed around the acetabular component. Long-term results of the reverse hybrid THA have not been published so far.

### 6.4.3.3 Results from arthroplasty registers

Data from the Swedish Arthroplasty Register revealed that in general THAs in younger patients (<55 years of age) had poorer survival than in older patients (Malchau et al. 2002). However, there were no results from that study comparing design concepts between age groups. In the cohort of patients who were younger than 55 years old at the time of the index operation, there was no significant difference between cemented, uncemented, and hybrid implants, though there was a trend towards higher survival rates for the uncemented and hybrid THAs. In another register-based study using data of the Norwegian Arthroplasty Register, Havelin and co-workers (2000) found that in younger patients (<60 years of age), the uncemented circumferentially porous-or hydroxyapatite (HA)-coated femoral stems had higher survival rates than the cemented types. They also found that cemented cups had better survival than uncemented porous-coated cups. They attributed this to higher rates of revision from wear and osteolysis among the latter. In Denmark, the risk of revision was reported to be higher with cemented than with uncemented implants in patients under 50 years of age (all diagnosis groups) (DHR 2004). In young patients, register-based results of different THR design concepts or designs have not been published so far.

### 6.4.3.4 Results in primary OA

There is only one published study that reports long-term results of cemented THA in young patients with primary OA (Devitt et al. 1997). In that study, Devitt and co-workers found a 64% survival rate for the Charnley LFA at 20 years. Survival of THAs was considerably poorer in patients with primary OA than in patients with RA (80% at 20 years). No one has published long-term results of uncemented THA in young

patients with primary OA. Furthermore, there are no register-based studies of THA in young patients with primary OA.

#### 6.4.3.5 Results in RA

There are only a few published studies reporting long-term results of THA in young patients with RA (Joshi et al. 1993, Devitt et al. 1997, Lehtimaki et al. 1997, Sochart and Porter 1997a, Lehtimaki et al. 1999, Lyback et al. 2004) (Table 4). Long-term results of cemented THA have only been published on the Charnley LFA, and survival rates have ranged from 91 to 99% at 10 years and from 77 to 96% at 20 years (Joshi et al. 1993, Devitt et al. 1997, Sochart and Porter 1997a). Long-term results of modern cemented THA concepts or modern third-generation cementing techniques have not been published for young patients with RA so far. Furthermore, there is only one published study on long-term results of uncemented THA in such patients (Lyback et al. 2004). In that study, Lybäck and colleagues reported a 97% survival rate at 10 years for the uncemented proximally porous-coated Bi-Metric stem (Biomet, Warsaw, In., USA): In contrast, 10 year survival rate of the uncemented smooth-threaded T-Tap cup (Biomet) was only 49% and that of the uncemented combination cup (porous-coated threaded) Romanus (Biomet) only 78%. Register-based studies of THA in young patients with RA have not been published.

**Table 4.** Survivorship of THA in young patients with rheumatoid arthritis.

| | THR brand | | | Age (mean) | FU | Wear [a] | Cementing method [b] | 10-year survival rates (%) | | | 20-year survival rates (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hips | Stem | Cup | | | | | Cup | Stem | THR | Cup | Stem | THR |
| Joshi et al. 1993 | 74 | Charnley | Charnley | <40 (32) [c] | 16[c] | - | 1 | - | - | >95[d] | 99 | >95[d] | 96 |
| Devitt et al. 1997 | 44 | Charnley | Charnley | <50 (42)[c] | 18[c] | - | 1 | - | - | >90[d] | - | - | 80 |
| Lehtimaki et al. 1997[f] | 186 | Charnley | Charnley | <68 (31) | - | - | 1 / 2 | 95 | 96 | 92 | - | - | - |
| Sochart and Porter 1997a | 100 | Charnley | Charnley | <30 (25) | 19 | 0.09 | 1 | 98 | 97 | 96 | 79 | 85 | 77 |
| Lyback et al. 2004[f] | 77 | Bi-Metric | T-Tap / Romanus | ≤60 (28) | 10 | - | Uncem. | 49/78[e] | 97 | 70 | - | - | - |

[a] Mean annual rate of linear wear.
[b] Cementing method: 1 = first-generation technique, 2 = second-generation technique
[c] Figures for all patients in the study.
[d] Estimated from a survival curve.
[e] T-Tap / Romanus
[f] All patients in the study had juvenile chronic arthritis.
FU = Mean follow-up time in years.

### 6.4.3.6 Results in developmental dysplasia of the hip

#### 6.4.3.6.1 High congenital hip dislocation

Published reports of THA in patients with DDH have included all three subtypes of the disease: dysplasia, low dislocation and high dislocation (Tronzo and Okin 1975, Harris et al. 1977, Lund and Termansen 1985, Harley and Wilkinson 1987, Garvin et al. 1991, Morscher 1995, DiFazio et al. 2002, Perka et al. 2004, Klapach et al. 2005). Confusion has thus arisen in efforts to analyze these results. There are only three earlier reports presenting the long-term results of THA in patients with high congenital dislocation (Hartofilakidis et al. 1998, Hartofilakidis and Karachalios 2004, Lai et al. 2005).

In a study of 84 consecutive THAs in patients with a high congenital dislocation, Hartofilakidis and Karachalios (2004) reported an 86.1% (±7.4%) survival rate for the acetabular component (both uncemented and cemented) at 15 years. However, the combined frequency of probable loosening as determined by radiographical examination plus actual revision of the acetabular component was 17.5%. Lai and co-workers (2005) reported the results of uncemented THA in 56 patients with a high congenital dislocation. In their study, uncemented cups had a 77% survival rate at 12 years. These authors reported that four of the nine cup revisions were performed because of excessive wear of the PE and five for aseptic loosening.

As most of the patients with a high congenital dislocation have a limp and poor abduction strength, it is important to report the effect of THA on these signs, which should also be measured objectively. In the largest available study of THA in congenital hip disease, Hartofilakidis and Karachalios (2004) did not report the proportion of patients limping nor did they report on the presence or absence of the Trendelenburg sign postoperatively. Bruce et al. (2000) published a study of a small number of congenitally dislocated hips operated on with a subtrochanteric segmental shortening osteotomy with the prosthesis in situ. They found all osteotomies united, but six of the eight patients had a positive Trendelenburg sign postoperatively. In a study of 21 THAs in severely dysplastic hips, Masonis et al. (2003) reported that only 17% of the patients could walk without a limp and 61% walked with a single cane after the operation. Other studies on femoral osteotomy in THA of severely dysplastic hips have included only a small number of patients with short-term to mid-term follow-up, and rarely have reported any data on abduction strength of the operated hips (Yasgur et al. 1997, Chareancholvanich et al. 1999b, Perka et al. 2000). In one paper, by Lai et al. (2005), the authors used preoperatively iliofemoral distraction with an external fixator for 8–17 days in 56 patients with unilateral high dislocation. With this method, shortening osteotomy of the femur was not required perioperatively. However, the authors did not provide any data on abduction strength of the hips postoperatively.

Paavilainen and co-workers have postulated, that a shortening osteotomy of the femur and transposition of the greater trochanter would be a safe surgical method for treating these patients (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997). In the short-term, the authors reported excellent functional results and radiographical union rates with this procedure (Paavilainen et al. 1990, Paavilainen et al.

1993, Paavilainen 1997). Hartofilakidis and Karachalios (2004) published a large study of 229 primary THAs in 168 patients with DDH. In this study, osteotomy of the greater trochanter was performed on all hips except for three with dysplasia, but femoral shortening osteotomy was not used for any hip. Fibrous union of the greater trochanter occurred in 22% of the hips that had a high dislocation, but non-union with migration of the greater trochanter in only one case (2%).

There is only one previous report by Hartofilakidis and Karachalios (2004) that presents the long-term survival rates of cemented femoral components in hips with a high congenital dislocation. They reported an 89.1% survival rate for cemented femoral components at 10 years and an 82.5% survival rate at 15 years. Similarly, long-term results of uncemented stems in the same patients have been published in one single study by Lai and co-workers (2005), who reported a 100% survival rate for a straight uncemented femoral component at 12 years.

#### 6.4.3.6.2 Hips with a previous Schanz osteotomy of the femur

Only four previous reports on THA include patients, who have previously undergone a Schanz osteotomy (Paavilainen et al. 1990, Paavilainen et al. 1993, Perka et al. 2000, Sener et al. 2002). In all of these studies, most of the patients had DDH. However, only a small minority of them had been previously treated with a Schanz osteotomy and no one has reported the results of THA only in patients with a previous Schanz osteotomy.

# 7. Aims of the present study

The main of purpose of this study was to evaluate the long-term survival of THA in young patients (<55 years at the time of primary THA) on a nation-wide level as well as the long-term outcome of cementless THA in young patients with severely dysplastic joints.

The specific aims of the studies were to assess:

1) The population-based survival of THA concepts in young patients with primary osteoarthritis and the factors affecting survival rates.

2) The population-based survival of modern uncemented THA designs in young patients with primary OA.

3) The population-based survival of THA concepts in young patients with rheumatoid arthritis and the factors affecting survival rates.

4) The long-term clinical and radiographical outcome of uncemented THA combined with distal advancement of the greater trochanter and femoral shortening osteotomy, in young patients with high congenital hip dislocation.

5) The long-term clinical and radiographical outcome of uncemented THA in young patients with severely dysplastic hips and a previous Schanz osteotomy of the femur.

# 8. PATIENTS AND METHODS

## 8.1 Patients

### 8.1.1 Register-based studies (I, II and III)

Between 1980 and 2001, a total of 74 492 THAs were recorded in the Finnish Arthroplasty Register. Of these operations, 4661 were performed for primary OA in 3657 patients under 55 years of age. For this reason, these 4661 THAs were included in the final analysis in study I. Between 1980–2003, information on 92 083 primary THAs were entered in the Finnish Arthroplasty Register. Of these operations, 5607 were performed for primary OA (II) and 2557 performed for RA (III) in patients under 55 years of age. Consequently, these were included in the final analysis. (Table 5)

**Table 5.** Summary of study design, type of data, patients and follow-up time.

| Study | I | II | III | IV | V |
|---|---|---|---|---|---|
| Study design | Prospective, observational | Prospective, observational | Prospective, observational | Partially prospective | Partially prospective |
| Type of data | Register-based | Register-based | Register-based | Clinical and radiographical | Clinical and radiographical |
| Patients (hips) | 3657 (4661) | 4884 (5607) | 1893 (2557) | 56 (68) [e] | 59 (68) [e] |
| Females (%) | 48% | 47% | 74% | 88% | 92% |
| Age [a] | 49 (16 – 54) | 49 (16 – 54) | 43 (14 – 54) | 54 (29-74) | 51 (29 – 69) |
| Follow-up (%) | - | - | - | 95% | 97% |
| Clinical [f] | - | - | - | 52 (64) | 58 (67) |
| Radiographic and telephone [f] | - | - | - | 3 (3) | 1 (1) |
| Telephone only [f] | - | - | - | 1 (1) | 0 |
| Mean [b] | 6.9 (0 – 22) | 7.0 (0 – 24) | 9.7 (0 – 24) | 12.3 (9 – 15) | 13.0 (9 – 18) |

[a] Mean age in years, range in parentheses.
[b] Mean follow-up in years, range in parentheses.
[c] Mean height in cm, range in parentheses.
[d] Mean weight in kilograms, range in parentheses.
[e] 28 patients (34 hips) were included both in study IV and in study V.
[f] Patients who participated at the last follow-up examination, hips in parentheses.

## 8.1.2 Clinical studies (IV and V)

Patients who had undergone THA at Orton Orthopaedic Hospital were included in the present study (IV and V) for the following conditions: Between January 1989 and December 1994, 75 primary THAs had been performed in 63 consecutive patients who had a high congenital dislocation of the hip according to the classification of Hartofilakidis et al. (1996) (IV). Between January 1988 and December 1995, 75 primary THAs had been performed in 65 consecutive patients with severely dysplastic hips, who had previously undergone a Schanz osteotomy (Schanz 1922) of the femur (V). Twenty-eight of these patients (34 hips) were included in both studies. (Table 5)

In study IV, all patients had a high congenital hip dislocation. Similarly, 55 (95%) patients (64 hips) had developmental dysplasia of the hip, three patients had a previous tuberculous arthritis of the hip, and one patient had congenital coxa vara in study V. (Table 6)

**Table 6.** Classification of the hips according to Eftekhar (1978) and Hartofilakidis et al. (1996).

| | | Eftekhar classification (n) | | | |
|---|---|---|---|---|---|
| **Hip disease** [a] | n | **A** | **B** | **C** | **D** |
| **Study IV** | | | | | |
| ***DDH*** | ***63*** | | | | |
| High dislocation | 63 | | | 24 | 47 |
| **Study V** | | | | | |
| ***DDH*** | ***63*** | | | | |
| Dysplasia | 4 | 4 | | | |
| Low dislocation[b] | 9 | | 9 | | |
| High dislocation | 51 | | | 18 | 33 |
| ***Tuberculosis*** [b] | ***3*** | | | | |
| Dysplasia | 1 | 1 | | | |
| High dislocation | 2 | | | 1 | 1 |
| ***Coxa vara*** [b] | ***1*** | | | | |
| Dysplasia | 1 | 1 | | | |

n = number of hips. DDH = developmental dysplasia of the hip.
[a] Classification of dysplasia according to Hartofilakidis et al[7]
[b] Hips with previous tuberculous coxarthritis or coxa vara were classified with the same methods.

The indications for arthroplasty were severe pain and/or considerable difficulty in walking and performing daily activities. Four patients in both studies died postoperatively from causes unrelated to the procedure. None of the deceased patients in study IV had undergone revision surgery, but two of the four deceased patients in study V had

undergone cup revision because of aseptic loosening of the cementless smooth-threaded acetabular component (3.3 and 4.4 years postoperatively). All of the remaining patients (59 in study IV and 61 in study V) were asked to participate in this follow-up study: 56 of the patients (95%) in study IV and 59 of patients (97%) in study V agreed to do so. The patients who declined to participate gave a lack of interest as their reason; none of the patients in study IV had undergone revision surgery, whereas two patients in study V had undergone revision of the femoral component.

## 8.2 Methods

### 8.2.1 Register-based studies (I, II and III)

The numbers and percentages of different implants used in the operations and the fixation method of each component (cemented or uncemented) were evaluated. (I and III)

The success rates of different implant design concepts were analyzed. In study I, stems were divided into five groups whereas the cups were divided into four groups for statistical comparisons. In study III, stems and cups were divided into four groups each, whereas the THRs were classified into three groups. Stems were classified as uncemented proximally circumferentially porous-coated, uncemented proximally circumferentially HA-coated, uncemented uncoated (including isoelastic, grit-blasted and sand-blasted uncemented stems), cemented (including polished, grit-blasted and sand-blasted cemented stems). In study I, uncemented extended porous-coated (porous-coating on more than half of the stem length) were also included in the design concept analysis. Cups were classified and grouped as uncemented porous-coated press-fit, uncemented HA-coated press-fit, uncemented smooth threaded and cemented all-poly. In study III, THRs were classified as press-fit porous-coated uncemented (proximally porous-coated uncemented stem and press-fit porous-coated uncemented cup), press-fit HA-coated uncemented (proximally HA-coated uncemented stem and press-fit HA-coated uncemented cup) and cemented (cemented stem and cemented all-polyethylene cup). Only implant designs used in 10 or more operations over the whole study period were included in the design concept analysis (I and III).

Epidemiological trends of THA in young patients with primary OA were analyzed for three time periods: 1980–1981, 1990–1991, and 2000–2001. In study I, the effects of implant fixation (cemented vs. uncemented) and implant concept on the survival of THA were analyzed separately for the whole study period and also for the decades 1980–1990 and 1991–2001.

The revision burden (expressed as a percentage by dividing the number of revisions done over a certain time period by the total number of primary and revision THAs performed over the same period) (Malchau et al. 2002) and indications for revision were analyzed (I and III).

Uncemented femoral and acetabular components that had been used in more than 100 operations during the study period were subjected to analysis. Only stem designs with a mean follow-up of more than five years, and more than 20 patients at risk at 10 years were included in the analysis. The uncemented isoelastic Mathys stem (RM Ma-

thys AG, Bettlach, Switzerland) which had previously given poor results was excluded from the study (Niinimaki et al. 1994). On the acetabular side, only press-fit cup designs with porous- or HA-coating were included; the Biomet Romanus cup commonly used in Finland, with porous-coating and screw-ring design, was also included. New cup brands, so called "second-generation" of modern press-fit porous- or HA-coated uncemented cups with short-term follow-up (mean follow-up <5 years) were also included in the study in order to determine whether the preliminary results of the new cup brands would differ from those of the older types. Similarly, stem and cup combinations used in more than 100 operations during the study period, including new designs with a short follow-up time, were included in the study. Uncemented smooth-threaded cups with well-documented poor results (Engh et al. 1990, Tallroth et al. 1993, Simank et al. 1997) were excluded. According to these inclusion and exclusion criteria, seven uncemented stem designs (Table 7a), 10 uncemented cup designs (Table 7b) and eight cup-stem combinations were included in the study (II).

**Table 7a.** Design, surface and material of the femoral components in the study.

| Stem design | Material | Surface | Design |
|---|---|---|---|
| ABG I | Titanium alloy | Prox. HA-coating | Anatomic |
| Anatomic Mesh | Titanium alloy | Prox. porous-coating | Anatomic |
| Bi-Metric | Titanium alloy | Prox. porous-coating | Straight |
| Lord Madréporique | Cobalt-chromium | Full porous-coating | Straight |
| PCA Std | Cobalt-chromium | Prox. porous-coating | Anatomic |
| Profile Porous | Titanium alloy | Prox. porous-coating | Anatomic |
| Spotorno | Titanium alloy | Grit-blasted | Straight, proximal fins |

**Table 7b.** Design, surface and material of the acetabular components in the study.

| Cup design | Material | Surface | Design | Screw-holes |
|---|---|---|---|---|
| ABG I | Titanium alloy | HA-coating | Hemispherical | Open |
| ABG II | Titanium alloy | HA-coating | Hemispherical | Closed |
| Biomet Mallory | Titanium alloy | Porous-coating | Hemispherical | Open |
| Biomet Romanus | Titanium alloy | Porous-coating | Screw-ring | Open |
| Biomet Universal | Titanium alloy | Porous-coating | Hemispherical | Open |
| Biomet Vision | Titanium alloy | Porous-coating | Hemispherical | Closed |
| Harris-Galante II | Titanium alloy | Porous-coating | Hemispherical | Open |
| Metasul Press-Fit | Tantalum | Trabecular | Hemispherical | No screw-holes |
| PCA Pegged | Cobalt-chromium | Porous-coating | Hemispherical | Open |
| Profile Duraloc | Titanium alloy | Porous-coating | Hemispherical | Open |

The effect of hospital type on THA survival was also studied by dividing the hospitals into subgroups according to the number of operations performed annually for primary OA in patients under 55 years of age, i.e., more than 10 operations or 10 operations or less (I).

## 8.2.2 Clinical studies (IV and V)

### 8.2.2.1 Clinical evaluation

The patients underwent detailed physical examination between August 2003 and December 2005. In addition to questions soliciting demographic data, they were also asked to assess their opinion on the result of the treatment on an arbitrary scale with five grades: 1 (very satisfied), 2 (satisfied), 3 (unsatisfied), 4 (very unsatisfied), and 5 (no opinion). The HHS was recorded (Harris 1969). The abduction strength of the hip was measured by three methods. First, the range of active abduction was assessed with the patient lying in the lateral decubitus position and elevating her or his affected extremity against gravity with the knee in extension. Second, the patient was asked to elevate her or his affected extremity against resistance by the physician's hand and the strength of abduction of the hip was graded according to the standard Medical Research Council scale (Seddon 1954) (MRC grades zero to five). Third, abduction strength was assessed by the Trendelenburg test. The extent of functional leg length discrepancy, if any, was measured by using wooden blocks under the shorter leg.

### 8.2.2.2 Operation technique

#### 8.2.2.2.1 Preparation of the femur

The appropriate operative method was selected according to the possible presence and the anatomical level of the Schanz osteotomy, and performed according to the methods described by Paavilainen et al (Paavilainen et al. 1990, Paavilainen et al. 1993, Paavilainen 1997). First, in cases of untreated high dislocation, a previous high-seated Schanz osteotomy or a bilateral low-seated osteotomy, a shortening osteotomy of the proximal part of the femur with transposition of the greater trochanter was performed (Figures 1 and 2). Second, in cases of unilateral low-seated Schanz osteotomy an angular correction and shortening osteotomy was performed at the level of the Schanz angle, and the stem was used as an intramedullary nail to stabilize the osteotomy site (Figure 1, C).

The first method was used in 61 hips (90%) in study IV and in 59 hips (87%) in study V. In this method a modified posterior approach was used with the patient in the lateral position. The proximal part of the vastus lateralis muscle was divided, and the posterior half was detached from the base of the greater trochanter to facilitate identification of the Schanz angle, at which level the femur was cut. The released proximal femur was split by an oscillating saw. The medial half of the femur containing the rudimentary or deformed femoral head and medial metaphysic was removed. The lateral half, containing the greater trochanter with intact attachments of the gluteus medius and anterior half of the vastus lateralis muscles was retracted anteriorly providing excellent access for preparing the acetabulum. Finally, after

reduction of the prosthesis the greater trochanter was advanced and fixed by two or three screws (Duo-Drive Head Cortical Screws®, 3.6 mm Self-Tapping (Howmedica, Limerick, Ireland)) with the hip in wide abduction. Laxity of the vastus lateralis due to the femoral shortening osteotomy was corrected by advancing the posterior half of the muscle to a more proximal insertion in the greater trochanter, and the loose anterior half was duplicated. If the medullary canal was found to be too narrow even for the smallest stem, the femur was split anteriorly and posteriorly for 8 to 10 cm with an opening wedge osteotomy, after which rasping was completed (Figure 1, D) (Paavilainen et al. 1993).

The second method was used only in unilateral cases with a previous low-seated Schanz osteotomy (4 hips in study IV and 8 hips in study V) because adequate limb-lengthening was not possible with the method described above. Metaphyseal segmental shortening with angular correction was performed in these hips to allow reduction and proper lengthening of the limb (Figure 1, C). A step-method was used to stabilize the osteotomy against rotation (Paavilainen et al. 1990). This operation was performed using a modified anterolateral approach described by Hardinge (Hardinge 1982) because it provides better access for the corrective osteotomy. The procedure was tedious, especially in the early cases, when rasping of the medullary canal had to be exact for both the proximal fragment and the distal femur. Moreover, the step-method of the osteotomy was time consuming.

#### 8.2.2.2.2 Preparation of the acetabulum

Preparation of the acetabulum was similar for both techniques. The proximal parts of the pubic and ischial bones and the tear-drop were exposed for identification of the true acetabulum and evaluation of the bone stock. The new acetabulum was created at the anatomical level between the pubic and ischial bone. If the sagittal diameter was too small at this level, the cup was placed in a more inferior position. An anterolateral bony prominence close to the junction of the pubic and iliac bones (anterior inferior iliac spine) offers reliable anterosuperior support, and the junction of the ischium to the ilium gives excellent posterosuperior support for the acetabular component. The superolateral rim between these is often concave and defective. However, it can be reinforced with a bulk bone graft from the removed femoral head or resected medial femoral metaphysis (Paavilainen 1997). The graft was fixed by screws. This was performed in 29 (43%) hips in study IV and in 42 hips (62%) in study V.

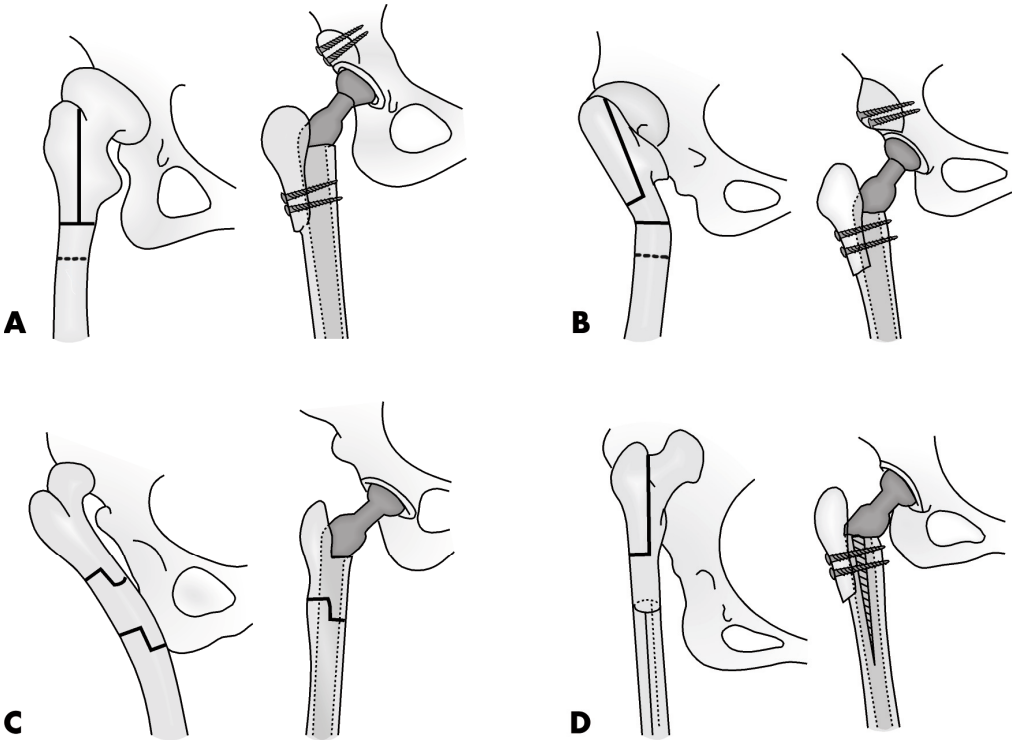



**Fig. 1.** Diagrams of the osteotomies used for various deformities of the femur. The femoral shaft is usually transected below the lesser trochanter, shown as transverse solid lines in A and B. A dotted line demonstrates the lowest level of possible osteotomy. **A:** Proximal shortening osteotomy with distal advancement of the greater trochanter (vertical solid line) for high congenital dislocations. **B:** Site of shortening osteotomy in hips with previous proximal Schanz osteotomy. **C:** Segmental shortening with angular correction for hips with a previous, more distal Schanz osteotomy. **D:** The femoral shaft is split both anteriorly and posteriorly if it is too narrow for the smallest stem.

Reliable fixation of the cup, i.e. at least 80% host bone coverage of the cup (Wolfgang 1990), was always achieved without bone grafting of the superolateral rim. Bone grafting was performed only to increase bone stock in the event of future revisions, not for primary fixation. In six (9%) hips, the pelvic bone was so thin that less than 80% host bone coverage of the cup was achieved; thus, the cup could not be reliably fixed in the remolded shallow acetabulum. In such cases, the central part of the medial wall was intentionally fractured and pushed medially while its periosteal attachments were preserved. The new medial wall was then augmented with cancellous bone (Hess and Umber 1978) and the acetabular component was impacted against the new medial wall. With this protrusion socket technique (Hess and Umber 1978), over 80% coverage of the cup was also achieved in the remaining six hips without superolateral bone grafting.

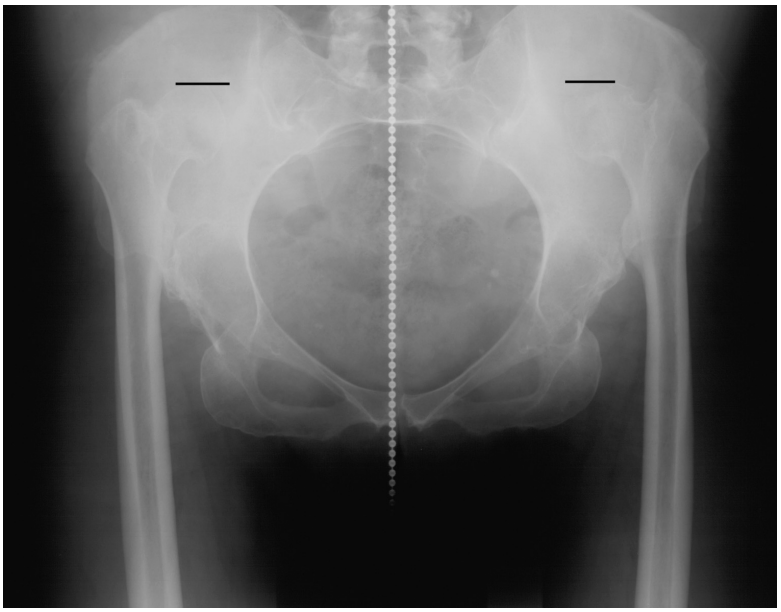


**Fig. 2-A and 2-B** A 52-year-old woman who had high congenital dislocation of both hips. **Fig. 2-A** Preoperative anteroposterior radiograph of both hips.

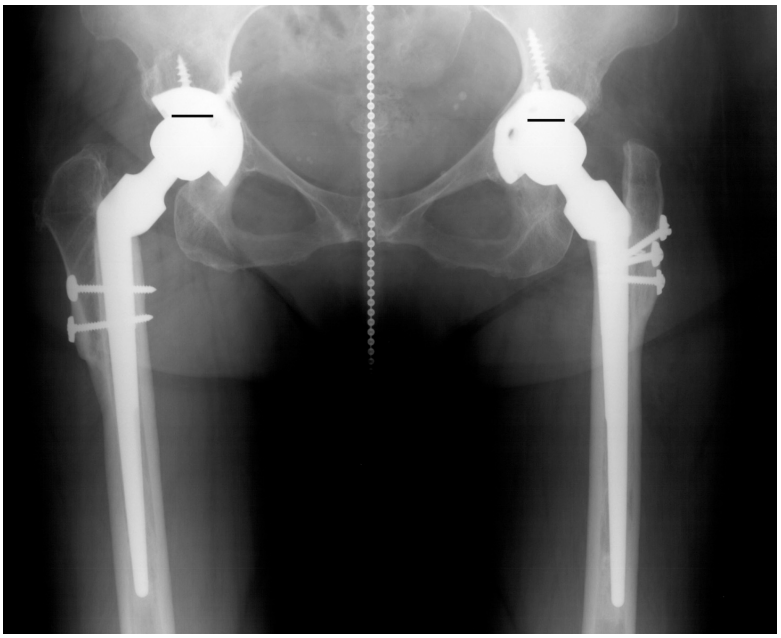


**Fig. 2-B** An AP pelvic radiograph taken 12 years after an uncemented total hip arthroplasty of the right hip, and 11 years after a similar procedure on the left hip. Both hips underwent femoral shortening and advancement of the greater trochanter. The pelvis is level. The resultant bilateral femoral shortening was 3.5 centimeters. There are no radiographic signs of loosening of the components and no signs of polyethylene wear.

In only a few hips (3 in study IV and 4 in study V) was THA possible without transposition of the greater trochanter or performing a metaphyseal step osteotomy.

The mean durations of the operations were 210 min (range, 95–340 min) and 215 min (range, 110– 340 min) in studies IV and V, respectively. Similarly, the mean perioperative blood losses were 2580 ml (range, 650–10000 ml) and 2411 ml (range, 450–10000 ml).

#### 8.2.2.2.3 Prosthetic components

The prosthetic components used in studies IV and V are shown in Table 8. Collared CDH (Biomet) stems were used since 1988 (n=46) and, beginning in 1993, collarless CDH stems (n=17) were used as well. The stem was chosen according to the anatomy of the proximal femur beyond the resection level. In study IV, a HexLoc™ polyethylene liner was used in all of the Biomet cups, and in study V it was used for the first 60 (88%) acetabular components, and a RingLoc™ liner was used in the last eight (Biomet Vision) cups. The mean outer diameter of the acetabular components was 46 mm (range, 40–56 mm). The outer diameter of the cup was ≤44 mm in 15 of the 68 hips in both studies (IV and V); and with these only 22 mm heads were available. In the larger cups, 28 mm heads were used.

**Table 8.** Prosthetic components used in studies IV and V.

| Design | Study IV | Study V |
|---|---|---|
| Stem | | |
| Lord Madréporique [a] | 1 | 1 |
| Biomet CDH [b] | 63 | 63 |
| Biomet Head-Neck [c] | 4 | 2 |
| Biomet Bi-Metric [d] | 0 | 2 |
| Cup | | |
| Lord [e] | 1 | 0 |
| Biomet T-Tap [e] | 8 | 18 [f] |
| Biomet Mallory [g] | 34 | 18 |
| Biomet Universal [h] | 25 | 24 |
| Biomet Vision [i] | 0 | 8 [j] |

[a] Extended porous-coated uncemented stem.
[b] Proximally circumferentially porous-coated stem, which has been specifically planned to dysplastic femora.
[c] Proximally circumferentially porous-coated stem with a …
[d] Proximally circumferentially porous-coated uncemented stem.
[e] Uncemented smooth-threaded cup.
[f] Biomet T-Tap cup was used in the first 18 hips in study V.
[g] A press-fit, porous-coated spherical uncemented cup with multiple open screw-holes and two? fins.
[h] A press-fit, porous-coated spherical uncemented cup with multiple open screw-holes.
[i] A press-fit, porous-coated spherical uncemented cup with multiple closed screw-holes and a RingLoc™ liner.
[j] Biomet Vision cup with RingLoc™ liner was used since 1994 (the last 8 hips in study V).

### 8.2.2.3 Radiographical evaluation (IV and V)

#### 8.2.2.3.1 Preoperative

The height of the dislocation was assessed by two methods. First, the three-stage grading proposed by Hartofilakidis et al. (1996) was applied. Second, the hips were also graded according to the four-stage Eftekhar classification (Eftekhar 1978).

All patients in study IV had a high congenital dislocation according to the grading proposed by Hartofilakidis et al. (1996). In 21 hips (31%), the congenital dislocation was graded as Eftekhar C and in 47 hips (69%) as Eftekhar D (Eftekhar 1978). In study V, in 6 hips (9%) congenital dislocation was classified as dysplastic (Eftekhar A) in six hips (9%), as low dislocation (Eftekhar B) in 9 hips (13%), and as high dislocation (19 Eftekhar C and 34 Eftekhar D) in 53 hips (78%).

#### 8.2.2.3.2 Postoperative

Anteroposterior and frog-leg view (Lauenstein) radiographs were evaluated by an independent observer. An anteroposterior radiograph was taken with the patient bearing weight and the feet parallel to each other (Turula et al. 1985). To obtain consistent and comparable radiographs, the x-ray beam was centered on the symphysis pubis. A lateral frog-leg radiograph was taken with the patient supine. The femoral and acetabular components were assessed by the method described by Johnston et al. (1990). The femoral components were classified as bone-ingrown, fibrous stable, or unstable according to the system described by Engh et al. (1987). Subsidence of the femoral component was defined as a change in position of >3 mm, and loosening of the acetabular component was defined as a change in alignment of >2° or a change in position of ≥2 mm. Radiolucent lines with a width of >1 mm at the component-bone interface were recorded in the three zones defined by DeLee and Charnley (1976). Osteolytic lesions were documented and classified by size and location (Gruen et al. 1979). Heterotopic ossification was classified according to the system of Brooker et al. (1973). The thickness of the PE liner was assessed using a magnifying glass and millimeter paper according to the method described by Charnley and Cupic (1973).

### 8.2.3 Statistical methods (I, II, III, IV and V)

Associations between categorical variables were analyzed by the Chi-square -test or the Fisher's exact –test, whichever was appropriate. Differences between two groups with respect to discrete quantitative variables were tested using the Mann-Whitney U-test. The normality of distributions was established by the Kolmogoroff-Smirnoff goodness-of-fit test with the Lilliefors method of significance correction. The independent samples t-test was applied for comparisons between two normally distributed groups. When the distributions were skewed, the Mann-Whitney U-test was applied (I and IV).

Preoperative and postoperative Harris hip scores were compared by the Wilcoxon signed rank-sum test (IV and V).

The end point criteria for survival were defined as revision when either one component or the whole implant was removed or exchanged. The end point for survival was defined as either revision (removal or exchange of one component or the whole implant) for any reason (including exchange

of liner), or as revision because of aseptic loosening. Kaplan-Meier survival data were used to calculate the survival probabilities of implants at different time points (Kaplan and Meier 1958). The survival data obtained in the Kaplan-Meier analysis were compared by the log-rank test (I, II, III IV and V).

The Cox multiple-regression model was used to evaluate differences between groups and to adjust for potential confounding factors (Cox 1972). The factors studied with the Cox model were as follows: implant fixation concepts (I), implant design concepts (I and III), implant designs (II), hospital THA volume (I), age group (I and III) and gender (I and III). All models included adjustment for differences in age (<46 and 46–54 years) and gender. When the effects of age, gender and hospital volume on the survival of implants were analyzed using the Cox regression model, adjustment was also made for implant design concepts (I and III). Cox regression analyses provided estimates of survival probabilities and revision risk ratios (RR) for different factors. Estimates from Cox analyses were used to calculate adjusted survival curves at mean values of the risk factors. The Wald test was used to calculate p-values for data obtained from the Cox multiple regression analysis.

Differences between groups were considered statistically significant, if the p-values were less than 0.05 in a two-tailed test (I, II, III, IV and V).

The statistical analyses were conducted with SPSS (versions 11.0 and 12.0) statistical software (SPSS Inc, Chicago, Ill., U.S.A.) for (I, II, III, IV and V).

### 8.2.4 Ethical considerations

Informed consent was obtained from all participants (IV and V). The authors obtained permission to perform these studies from the ethical committee of the hospital district in which the studies were conducted (I, II, III, IV and V).

# 9. Results

## 9.1 Register-based studies (I, II and III)

### 9.1.2 Primary operation

#### 9.1.2.1 Patient characteristics

Of the THAs, 82% in study I (n=3811) and 51% (n=1293) in study III were performed in patients aged 46–54 years. The rest were performed on patients aged <46 years. Moreover, 54% (n=2508) of THAs in study I and 52% (n=1331) in study III were performed on the right hip.

The number of hospitals performing THAs for primary OA in young patients (I) increased over the study period, from 30 at the beginning of the period (1980-1981) to 49 at the beginning of the next decade (1990-1991). This figure rose to 64 at the end of the study period (2000-2001). Similarly, the number of hospitals performing THAs for RA in young patients (III) rose from 19 at the beginning of the study period (1980–1981) to 32 at the beginning of the next decade (1991-1992), and remained at this level to the end of the study period (2002-2003). Over the whole study period, only 5 hospitals in Finland (3 university hospitals, one hospital run by a private foundation and one central hospital) performed more than 10 THAs annually for primary OA (I), and only one hospital (run by a private foundation) performed more than 20 THAs annually for RA (III) on patients under 55 years of age. During the last time-period (2000–2001) analyzed in study I, 52 of the 64 hospitals studied, performed fewer than 10 THAs annually for primary OA in young patients. Similarly, only 6 of the 32 hospitals studied performed more than 20 THAs annually for RA in young patients during 2002–2003 (III).

#### 9.1.2.2 Femoral components

Uncemented femoral components were used in a majority of the THAs performed in young patients both with primary OA (I) and RA (III) in Finland during the study period (Table 9). At the end of the study period (2000–2001 for OA, 2002-2003 for RA), the 3 most common stem brands (Bi-Metric, ABG II and Exeter Universal) accounted for 72% and 70% of all stems in patients with OA (I) and RA (III), respectively. The proportion of uncemented stems implanted in patients of both groups rose dramatically from the beginning of the study to the early 1990s.

#### 9.1.2.3 Acetabular components

Uncemented acetabular components were used in a majority of the THAs performed in young patients both with primary OA (I) and RA (III) in Finland during the study period (Table 9). At the end of the study periods (2000–2001 for OA and 2002–2003 for RA), the 3 most common cup brands accounted for 64% of all cups implanted for OA (I) and 46% of all cups implanted for RA (III). The proportion of uncemented cups also rose markedly from the beginning of the study period to the early 1990s. However, since the beginning of the 21st century the use of cemented cups appears to have become more popular for both patient groups. A majority of the femoral and acetabular components were used in less than 20 operations during the whole study period.

**Table 9.** Femoral and acetabular components used in young patients with primary OA and RA in Finland over the study period [a].

| | Femoral components | | | Acetabular components | | |
|---|---|---|---|---|---|---|
| | N [b] | Uncem. | < 20 operations[c] | N [b] | Uncem. | < 20 operations[c] |
| Primary OA (study I) | 73 | 78% | 69% | 79 | 82% | 59% |
| RA (study III) | 71 | 60% | 73% | 83 | 82% | 72% |

[a] Study period was 1980-2001 in patients with primary OA and 1980-2003 in patients with RA.
[b] Number of different implant designs used over the study period.
[c] Number of implant designs used in less than 20 operations over the whole study period.
OA = osteoarthritis. RA = rheumatoid arthritis.

### 9.1.3 Revision operation

Aseptic loosening was the most common reason for revision both in young patients with primary OA (I) and in patients with RA (III) (Table 10). The revision burden was higher in patients with RA than in patients with primary OA (19.1% vs. 13.2%).

Reasons for revisions of uncemented implant designs are presented in Tables 11a and 11b (II). Over the study period 90% (37/39) of the revisions of the PCA Pegged cups were performed due to aseptic loosening. In contrast, 52% (23/44) of the Biomet Romanus and 67% (14/21) of the Biomet Mallory cups revised were due to other reasons (including exchange of liner).

**Table 10.** THA revisions in patients with diagnoses of primary osteoarthritis or rheumatoid arthritis and aged <55 years at the time of the primary operation in Finland [a].

| | Primary OA (study I) | RA (study III) |
|---|---|---|
| Follow-up [b] | 6.9 (0 - 22) | 9.7 (0 - 24) |
| Total number of revisions | 709 | 605 |
| Revision burden [c] | 13.2% | 19.1% |
| Reasons for revision | | |
| Aseptic loosening | 82% | 82% |
| Dislocation | 2.7% | 3.3% |
| Infection | 2.7% | 2.8% |
| Malposition | 2.3% | 1.0% |
| Fracture of implant | 3.0% | 1.2% |
| Periprosthetic fracture | 1.1% | 1.8% |
| Other (incl. exchange of liner) | 6.3% | 8.3% |

[a] Study period was 1980-2001 in patients with primary OA and 1980-2003 in patients with RA.
[b] Mean follow-up in years, range in parentheses.
[c] Expressed as a percentage by dividing the number of revisions done over a certain period by the total number of primary and revision THAs performed over the same period.
OA = osteoarthritis. RA = rheumatoid arthritis.

**Table 11a.** Reasons for revision of femoral components in study II.

| Stem brand | Operations (n) | N of revisions (revision burden %) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Aseptic loosening | Infection | Dislocation | Malposition of stem | Fracture of stem | Fracture of bone | Total |
| ABG I | 390 | 2 (0.5) | - | 4 (1.0) | - | - | - | 6 (1.5) |
| Anatomic Mesh | 135 | 13 (8.5) | - | - | 1 (0.7) | 4 (2.6) | - | 18 (11.8) |
| Bi-Metric | 1982 | 37 (1.8) | 7 (0.3) | 15 (0.7) | 12 (0.6) | - | 2 (0.1) | 73 (3.6) |
| Lord Madréporique | 286 | 26 (8.3) | 1 (0.3) | | | 2 (0.6) | | 29 (9.2) |
| PCA Std | 111 | 9 (7.4) | 1 (0.8) | - | - | 1 (0.8) | - | 11 (9.0) |
| Profile Porous | 115 | - | 1 (0.8) | 4 (3.2) | 2 (1.6) | 2 (1.6) | - | 9 (7.3) |
| Spotorno | 108 | 1 (0.9) | - | 1 (0.9) | - | 1 (0.9) | 1 (0.9) | 4 (3.6) |

**Table 11b.** Reasons for revision of acetabular components in study II.

| Cup brand | Operations (n) | N of revisions (revision burden%) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Aseptic loosening | Infection | Dislocation | Malposition of the cup | Other reasons [a] | Total |
| ABG I | 108 | 4 (3.1) | 0 | 4 (3.1) | 0 | 14 (10.8) | 22 (16.9) |
| ABG II | 473 | 1 (0.2) | 1 (0.2) | 0 | 0 | 0 | 2 (0.4) |
| Biomet Mallory | 110 | 5 (3.8) | 0 | 1 (0.8) | 1 (0.8) | 14 (10.7) | 21 (16.0) |
| Biomet Romanus | 114 | 18 (11.4) | 1 (0.6) | 2 (1.3) | 0 | 23 (14.6) | 44 (27.8) |
| Biomet Universal | 898 | 34 (3.4) | 2 (0.2) | 12 (11.9) | 8 (0.8) | 58 (5.7) | 114 (11.3) |
| Biomet Vision | 418 | 0 | 1 (2.4) | 1 (2.4) | 1 (2.4) | 1 (2.4) | 4 (0.9) |
| Harris-Galante II | 277 | 16 (5.1) | 2 (0.6) | 3 (1.0) | 1 (0.3) | 15 (4.8) | 37 (11.8) |
| Morscher Press-Fit | 136 | 2 (1.4) | 0 | 1 (0.7) | 0 | 0 | 3 (2.2) |
| PCA Pegged | 122 | 37 (23.0) | 1 (0.6) | 0 | 0 | 1 (0.6) | 39 (24.2) |
| Profile Duraloc | 145 | 1 (0.7) | 0 | 3 (2.0) | 1 (0.7) | 3 (2.0) | 8 (5.2) |

[a] Including exchange of liner.

## 9.1.4 Follow-up results for all primary operations

### 9.1.4.1 Stem fixation (I)

In young patients with primary OA, Kaplan-Meier analysis of the total data showed that the survival of uncemented stems was significantly higher than that of cemented stems ($p<0.001$; all revisions; $p<0.001$, aseptic loosening). The Cox regression analysis, with or without adjustment for age and gender, gave similar results.

Kaplan-Meier analysis of stems implanted during the first decade (1980–1990) of the study period showed that survival of uncemented stems was notably better than that of cemented stems ($p=0.002$, all revisions; $p<0.001$, aseptic loosening). In Kaplan-Meier analysis of the last decade, there was a significant difference in over-

all survival in favour of uncemented stems, when aseptic loosening was used as the end point ($p<0.001$). However, the difference in survival rates between uncemented and cemented stems was not statistically significant when the end point was defined as any revision ($p=0.2$). Similar results were obtained from the Cox regression analysis, both with and without adjustment for age and gender.

### 9.1.4.2 Stem design concepts (I, and III)

#### 9.1.4.2.1 Whole study period

Data for the stem design concepts for the whole study period are shown in Tables 12 and 13.

When the whole study period was analyzed, all stem design concepts had a >90% survival rates at 7 years when aseptic loosening was taken as the end point, both in patients with primary OA (I) and in patients with RA (III) (Table 12). For patients with primary OA (I), only proximally porous-coated uncemented stems had >95% survival rate at 10 years. Moreover, for patients with RA (III), the survival rate for proximally porous-coated stems was 89% (95% CI 83–94), and that of cemented stems 84% (95% CI 81–87) at 15 years. However, the survival rate of uncoated stems had declined to 71% (95% CI 63–79) over the same period. Cox regression analysis (with adjustment for age and gender) revealed that both proximally porous-coated, extended porous-coated and proximally HA-coated uncemented stems had a significantly lower risk of revision than cemented stems in patients with OA (I) (Figure 3 and Table 12). Furthermore, proximally porous-coated uncemented stems had a significantly ($p<0.001$) lower risk of revision than cemented stems in patients with RA (III) (Figure 4 and Table 12). In contrast, uncoated uncemented stems had an increased risk of revision as compared to cemented stems in patients with RA (III) (Figure 4 and Table 12). The Cox regression model indicated that the survival of proximally porous-coated uncemented stems was already better than that of cemented stems during the first 7 years of follow-up. Even after 7 years of follow-up, there was a trend for porous-coated stems to perform better than cemented ones.

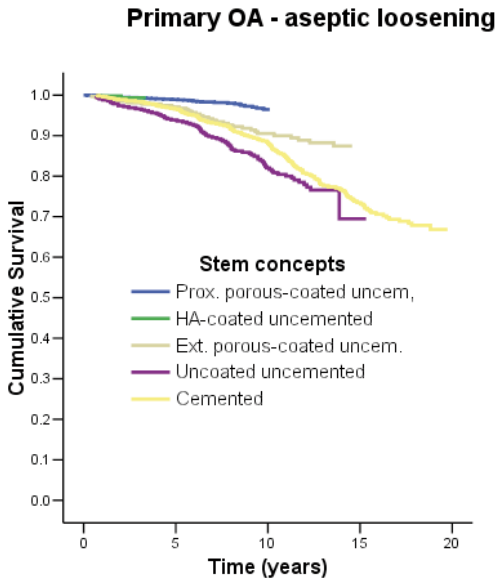



**Fig 3.** Cox-adjusted survival curves of 4315 stems in young patients with primary OA, with stem design concept as the strata factor. The end point defined as stem revision due to aseptic loosening. Adjustment made for age and gender.

With any stem revision taken as the end point, only proximally porous-coated uncemented stems had a >90% survival rate at 10 years in both patient groups (I and III)

(Table 13). In patients with primary OA (I), both proximally and extended porous-coated uncemented stems had better overall survival than cemented stems (Table 13). There was also a trend towards better survival of HA-coated uncemented stems than for cemented stems, but the difference just failed to be statistically significant (p=0.05). In the Cox model of patients with RA (III), proximally porous-coated uncemented stems were found to have a decreased risk of stem revision and uncoated uncemented stems an increased risk of stem revision as compared to cemented stems (Table 13).

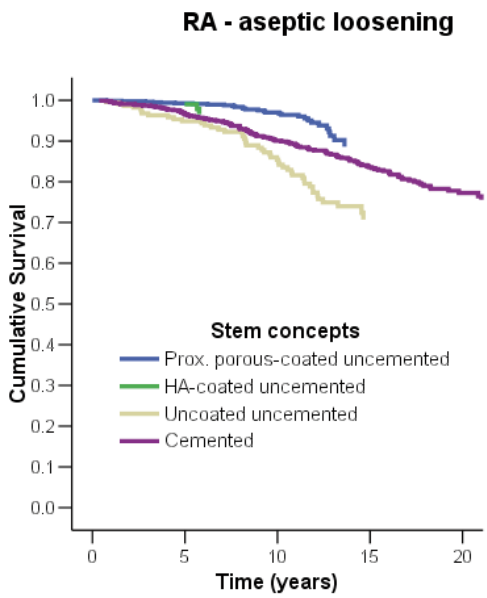



**Fig 4.** Cox-adjusted survival curves of 2232 stems in young patients with RA, with stem design concept as the strata factor. The end point defined as stem revision due to aseptic loosening. Adjustment made for age and gender.

#### 9.1.4.2.2 Primary OA, period 1980–1990 (I)

Only proximally and extended porous-coated uncemented stems had >90% survival rates in patients with primary OA at 10 years. In the Cox regression analysis, both proximally and extended porous-coated uncemented stems had a lower risk of revision than cemented stems when aseptic loosening was taken as the end point (Figure 5 and Table 14). With any stem revision as the end point, 10 year survival rates of all concepts declined to less than 90%. Moreover, the Cox analysis revealed that extended porous-coated uncemented stems still had a significantly lower risk of revision than cemented stems. It should be noted that HA-coated uncemented stems were not implanted during the 1980s.

#### 9.1.4.2.3 Primary OA, period 1991–2001 (I)

When stems implanted over the 1991–2001 period were analyzed, only proximally porous-coated uncemented stems had >95% survival rates at 10 years when aseptic loosening was taken as the end point (Figure 6, Table 14). Using the Cox regression analysis, both proximally porous-coated and HA-coated uncemented stems were found to have lower risks of revision than cemented stems. In contrast, uncoated uncemented stems had a significantly increased risk of revision as compared to cemented stems. With all revisions taken as the end point, there were non-significant trends towards a lower risk of revision for proximally porous-coated (p=0.09) and HA-coated uncemented stems (p=0.07) as compared to cemented stems.

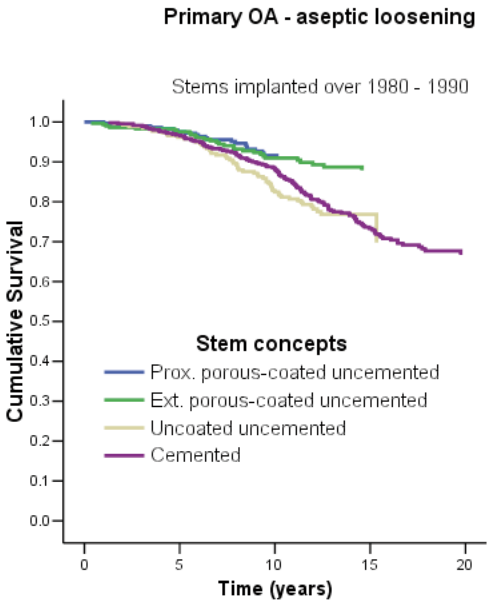



**Fig 5.** Cox-adjusted survival curves calculated for 1421 stems implanted during 1980-1990, with stem design concept as the strata factor. The end point defined as stem revision due to aseptic loosening. Adjustment made for age and gender.

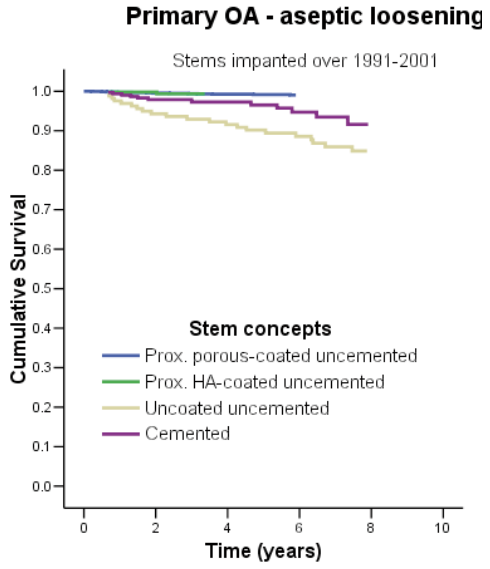



**Fig 6.** Cox-adjusted survival curves calculated for 3240 stems implanted during 1990-2001, with stem design concept as the strata factor. The end point defined as stem revision due to aseptic loosening. Adjustment made for age and gender. Only 31 extended porous-coated stems were implanted during 1991-2001; they are not included in the analysis.

#### 9.1.4.2.4 Cohort effect among stem design concepts (I and III)

In patients with primary OA (I), the Cox regression analysis showed that proximally porous-coated uncemented stems implanted during 1991–2001 had a significantly lower risk of revision than stems of the same design concept implanted during the first decade (1980–1990) of the study period when all revisions ($p<0.001$) or aseptic loosening ($p<0.001$) were taken as the end points (Table 14). There were no significant differences in survival between the cohorts of 1980–1990 and 1991–2001 for cemented and uncoated uncemented stems.

The Cox regression analysis did not reveal any differences in stem design concept survival between the cohorts of 1980–1991 and 1992–2003 for patients with RA (III).

**Table 12.** Survival of stem design concepts in young patients with primary OA and RA. Endpoint defined as revision due to aseptic loosening of the stem. 7-, 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| | | | | | | | | | | | Follow-up < 7 yrs | | Follow-up > 7 yrs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stem concept** | **N*** | **MF yr** | **AR 7 yr** | **% 7-year survival (95 % CI)** | **AR 10 yr** | **% 10-year survival (95 % CI)** | **AR 15 yr** | **% 15-year survival (95 % CI)** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** |
| *Primary osteoarthritis* | | | | | | | | | | | | | | |
| Prox. porous-coated uncemented | 35 / 2197 | 5.9 | 737 | 98 (98 - 99) | 225 | 97 (96 - 98) | - | - | 0.2 (0.2 - 0.3) | <0.001 | - | - | - | - |
| Ext. porous-coated uncemented | 31/ 318 | 11.3 | 240 | 94 (91 - 97) | 186 | 90 (87 – 94) | - | - | 0.5 (0.3 - 0.7) | <0.001 | - | - | - | - |
| Prox. HA-coated uncemented | 2 / 526 | 3.4 | 41 | 99 (98 - 100) | 0 | - | - | - | 0.1 (0.0 - 0.6) | 0.006 | - | - | - | |
| Uncoated uncemented | 76 / 441 | 9.3 | 309 | 90 (87 – 93) | 206 | 82 (78 - 86) | - | - | 1.2 (0.9 - 1.6) | 0.3 | - | - | - | - |
| Cemented | 132 / 833 | 9.6 | 462 | 93 (91 – 95) | 358 | 88 (86 – 91) | - | - | 1.0 | - | - | - | - | - |
| *Rheumatoid arthritis* | | | | | | | | | | | | | | |
| Prox. porous-coated uncemented | 29 / 913 | 8.0 | 588 | 99 (98 - 100) | 370 | 97 (96 - 99) | 29 | 89 (83 - 94) | 0.4 (0.3 - 0.6) | <0.001 | 0.2 (0.1 – 0.5) | <0.001 | 0.6 (0.4 – 1.1) | 0.08 |
| Prox. HA-coated uncemented | 3 / 211 | 4.6 | 55 | 96 (92 - 100) | 9 | - | - | - | 0.4 (0.1 - 1.2) | 0.09 | 0.5 (0.1 – 1.5) | 0.2 | - | NA |
| Uncoated uncemented | 46 / 230 | 10.5 | 182 | 93 (89 - 96) | 150 | 86 (80 - 91) | 49 | 71 (63 - 79) | 1.7 (1.2 - 2.5) | 0.002 | 1.5 (0.8 – 2.7) | 0.2 | 2.0 (1.3 – 3.0) | 0.002 |
| Cemented | 125 / 878 | 12.4 | 679 | 95 (93 - 96) | 556 | 90 (88 - 92) | 379 | 84 (81 - 87) | 1.0 | - | 1.0 | - | 1.0 | - |

* Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other stem brands compared to the cemented stems; adjustment made for age and gender). NA = not assigned.

**Table 13.** Survival of stem design concepts in young patients with primary OA and RA. Endpoint defined as any stem revision. 7-, 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| | | | | | | | | | | Follow-up < 7 yrs | | Follow-up > 7 yrs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stem concept** | **N*** | **MF yr** | **AR 7 yr** | **% 7-year survival (95 % CI)** | **AR 10 yr** | **% 10-year survival (95 % CI)** | **AR 15 yr** | **% 15-year survival (95 % CI)** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** |
| *Primary osteoarthritis* | | | | | | | | | | | | | | |
| Prox. porous-coated uncemented | 106 / 2197 | 5.9 | 739 | 95 (93 - 96) | 225 | 91 (89 – 93) | - | - | 0.6 (0.4 - 0.8) | <0.001 | - | - | - | - |
| Ext. porous-coated uncemented | 37 / 318 | 11.3 | 240 | 93 (90 – 96) | 186 | 89 (85 – 93) | - | - | 0.5 (0.3 - 0.7) | <0.001 | - | - | - | - |
| Prox. HA-coated uncemented | 8 / 526 | 3.4 | 41 | 95 (91 – 99) | 0 | - | - | - | 0.5 (0.2 - 1.0) | 0.05 | - | - | - | |
| Uncoated uncemented | 89 / 441 | 9.3 | 310 | 88 (85 – 91) | 206 | 80 (75 – 84) | - | - | 1.2 (0.9 - 1.6) | 0.2 | - | - | - | - |
| Cemented | 154 / 833 | 9.6 | 462 | 92 (90 – 94) | 359 | 87 (84 - 90) | - | - | 1.0 | - | - | - | - | - |
| *Rheumatoid arthritis* | | | | | | | | | | | | | | |
| Prox. porous-coated uncemented | 43 / 913 | 8.0 | 588 | 97 (96 - 98) | 370 | 95 (93 - 97) | 29 | 87 (82 - 92) | 0.5 (0.4 – 0.8) | 0.01 | 0.5 (0.3 – 0.9) | 0.01 | 0.6 (0.4 – 0.9) | 0.03 |
| Prox. HA-coated uncemented | 5 / 211 | 4.6 | 55 | 95 (91 - 99) | 9 | - | 0 | - | 0.6 (0.2 – 1.4) | 0.2 | 0.7 (0.3 – 1.7) | 0.4 | - | NA |
| Uncoated uncemented | 56 / 230 | 10.5 | 182 | 90 (86 - 94) | 151 | 82 (76 - 87) | 49 | 67 (59 - 75) | 1.9 (1.4 – 2.6) | <0.001 | 1.9 (1.1 – 3.1) | 0.01 | 1.8 (1.2 – 2.8) | 0.003 |
| Cemented | 146 / 878 | 12.4 | 679 | 94 (93 - 96) | 558 | 89 (87 - 92) | 379 | 81 (78 - 84) | 1.0 | - | 1.0 | - | 1.0 | - |

* Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other stem brands compared to the cemented stems; adjustment made for age and gender). NA = not assigned.

**Table 14.** Survival of stem concepts in young patients with primary osteoarthritis. 7- and 10-year survival rates obtained from the Kaplan-Meier analysis.

| | | All revisions | | | | Aseptic loosening | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Stem concept** | **N** | **% 7-year survival (95% CI)** | **% 10-year survival (95% CI)** | **ARR (95 % CI)** | **p** | **% 7-year survival (95% CI)** | **% 10-year survival (95% CI)** | **ARR (95 % CI)** | **p** |
| *1980-1990* | | | | | | | | | |
| Prox. porous-coated uncemented | 304 | 92 (89 – 95) | 83 (79 – 88) | 0.8 (0.5 – 1.1) | 0.2 | 96 (93 - 98) | 92 (88 - 95) | 0.5 (0.3 – 0.7) | 0.001 |
| Ext. porous-coated uncemented | 287 | 94 (91 - 97) | 89 (86 – 93) | 0.4 (0.3 – 0.7) | <0.001 | 95 (92 - 98) | 91 (87 - 94) | 0.4 (0.3 – 0.6) | <0.001 |
| Uncoated uncemented | 266 | 90 (86 – 93) | 80 (75 – 85) | 1.1 (0.8 – 1.5) | 0.5 | 92 (88 – 95) | 82 (78 - 87) | 1.1 (0.8 – 1.5) | 0.7 |
| Cemented | 472 | 93 (90 – 95) | 87 (84 – 90) | 1.0 | - | 93 (91 - 96) | 88 (85 - 91) | 1.0 | - |
| *1991-2001* | | | | | | | | | |
| Prox. porous-coated uncemented | 1893 | 95 (94 – 97) | 94 (93 – 96) | 0.6 (0.4 – 1.1) | 0.09 | 99 (99 – 100) | 99 (99 – 100) | 0.2 (0.1 – 0.4) | <0.001 |
| HA-coated uncemented | 526 | 95 (91 – 99) | - | 0.5 (0.2 – 1.1) | 0.07 | 99 (98 - 100) | - | 0.2 (0.0 – 0.7) | 0.01 |
| Uncoated uncemented | 175 | 85 (80 – 91) | 83 (76 – 89) | 2.1 (1.1 – 4.1) | 0.02 | 87 (81 – 92) | 85 (79 - 91) | 2.4 (1.2 – 5.0) | 0.02 |
| Cemented | 361 | 92 (87 -96) | 90 (84 – 96) | 1.0 | - | 94 (89 – 98) | 92 (86 - 97) | 1.0 | - |

N = number of primary operations. ARR = Adjusted risk ratio from the Cox regression analysis (other stem brands compared to the cemented stems; adjustment made for age and gender).

### 9.1.4.3 Uncemented stem designs (II)

The Bi-Metric, the CLS Spotorno, the ABG I and also the Profile Porous stems had >95% survival rates at 10 years when aseptic loosening was taken as the end point (Table 15). At 15 years, survival rate of the Bi-Metric stem was still 95% (95% CI 93–97), and that of the PCA Std stem 90% (95% CI 84–97), whereas the 15 year survival rate of the extended porous-coated Lord Madréporique stem was 91% (95% CI 88–94). Survival of the other stem brands were compared with the Bi-Metric stem (reference stem): Cox regression analysis (adjusting for age and gender) indicated that both the Lord Madréporique stem (RR 2.2, 95% CI 1.3–3.7; p=0.004) and the Anatomic Mesh stem (RR 2.8, 95% CI 1.5–5.4; p=0.002) had significantly higher risks of revision than the Bi-Metric stem (Figure 7).

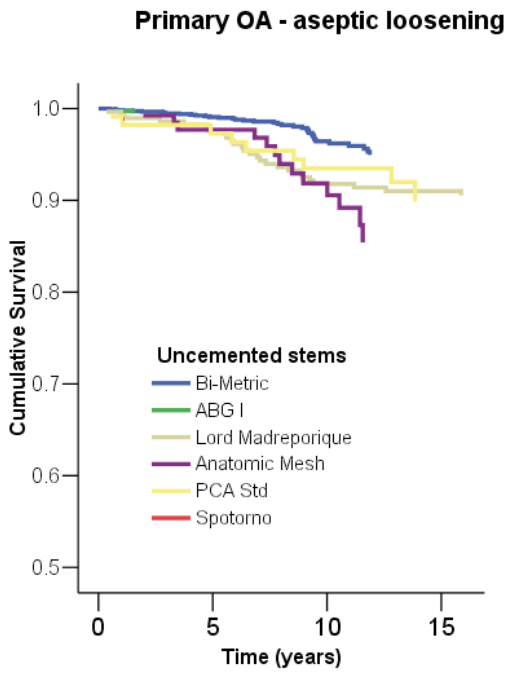



**Fig 7.** Cox-adjusted survival curves of 3127 stems in patients under 55 years of age, with stem design as the strata factor. The end point defined as stem revision due to aseptic loosening. Adjustment made for age and gender. Curve of the Profile Porous stem is not displayed, as it had a 100% survival rate at 10 years.

All stem brands had >90% survival rates at 10 years, using stem revision for any reason as the end point (Table 15). The Bi-Metric stem had a 92% (95% CI 90–94) survival rate at 15 years. Using the Cox model, the Anatomic Mesh stem was found to have a 2.2-fold (95% CI 1.3–3.7; p=0.004) increased risk of stem revision as compared to the Bi-Metric stem.

**Table 15.** Survival and adjusted risk ratio for revision of stem designs in young patients with primary OA. Endpoint was defined as revision due to aseptic loosening of the stem or stem revision for any reason. 7- 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| Stem design | N* | MF yr | AR 7 yr | % 7-year survival (95 % CI) | AR 10 yr | % 10-year survival (95 % CI) | AR 15 yr | % 15-year survival (95 % CI) | Adjusted RR for revision (95 % CI) | p |
|---|---|---|---|---|---|---|---|---|---|---|
| *Aseptic loosening* | | | | | | | | | | |
| ABG I | 2 / 390 | 5.5 | 128 | 99.5 (98.8 - 100) | 39 | 99.5 (98.8 - 100) | 0 | - | 0.4 (0.1 - 1.7) | 0.2 |
| Anatomic Mesh | 13 / 135 | 9.8 | 116 | 96.9 (93.8 - 99.9) | 80 | 92.0 (86.9 - 97.1) | 3 | - | 2.8 (1.5 - 5.4) | 0.002 |
| Lord Madréporique | 26 / 286 | 15.8 | 264 | 94.6 (92.0 - 97.3) | 248 | 91.7 (88.4 - 94.9) | 219 | 90.9 (87.5 - 94.3) | 2.2 (1.3 - 3.7) | 0.004 |
| Profile Porous | 0 / 115 | 9.3 | 100 | 100 | 58 | 100 | 2 | - | - | NA |
| PCA Standard | 9 / 111 | 13.0 | 102 | 95.4 (91.4 - 99.3) | 96 | 93.4 (88.7 - 98.1) | 38 | 90.1 (83.6 - 96.5) | 1.8 (0.9 - 3.9) | 0.1 |
| CLS Spotorno | 1 / 108 | 5.9 | 45 | 98.9 (96.8 - 100) | 28 | 98.9 (96.8 - 100) | 9 | - | 0.5 (0.1 - 3.8) | 0.5 |
| Bi-Metric | 37 / 1982 | 6.6 | 937 | 98.6 (97.9 - 99.2) | 508 | 96.4 (95.0 - 97.7) | 117 | 94.9 (93.0 - 96.8) | 1.0 | - |
| *Any stem revision* | | | | | | | | | | |
| ABG I | 6 / 390 | 5.5 | 128 | 98.9 (97.8 - 100) | 39 | 97.4 (94.2 - 100) | 0 | - | 0.5 (0.2 - 1.2) | 0.1 |
| Anatomic Mesh | 18 / 135 | 9.8 | 116 | 95.4 (91.4 - 99.3) | 80 | 90.6 (85.2 - 95.9) | 3 | - | 2.2 (1.3 - 3.7) | 0.004 |
| Lord Madréporique | 29 / 286 | 15.8 | 264 | 94.3 (91.5 - 97.0) | 248 | 91.3 (88.0 - 94.6) | 219 | 89.8 (86.2 - 93.4) | 1.4 (0.9 - 2.2) | 0.2 |
| Profile Porous | 9 / 115 | 9.3 | 101 | 93.6 (89.1 - 98.2) | 58 | 92.6 (87.7 - 97.6) | 2 | - | 1.4 (0.7 - 2.8) | 0.3 |
| PCA Standard | 11 / 111 | 13.0 | 102 | 95.4 (91.4 - 99.3) | 96 | 92.5 (87.5 - 97.5) | 38 | 88.3 (81.5 - 95.1) | 1.3 (0.7 - 2.5) | 0.4 |
| CLS Spotorno | 4 / 108 | 5.9 | 45 | 95.9 (91.1 - 100) | 28 | 95.9 (91.1 - 100) | 9 | - | 1.1 (0.4 - 2.9) | 0.9 |
| Bi-Metric | 73 / 1982 | 6.6 | 938 | 96.5 (95.5 - 97.5) | 508 | 93.7 (92.0 - 95.3) | 117 | 92.2 (90.2 - 94.3) | 1.0 | - |

*Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other stem designs compared to the Bi-Metric stem; adjustment made for age and gender).

### 9.1.4.4 Cup fixation (I)

We found no differences in survival rates between cemented and uncemented cups in young patients with primary OA, using either the Kaplan-Meier analysis or the Cox regression model to analyse the whole study period.

The Kaplan-Meier analysis of cups implanted during the first decade (1980–1990) revealed that overall survival of cemented cups was significantly better than that of uncemented cups (all revisions, p=0.01; aseptic loosening, p=0.02). Conformation of this was obtained using the Cox regression analysis, which gave similar results (with or without adjustment for age and gender).

Neither the Kaplan-Meier analysis nor the Cox regression method revealed any differences in survival rates between cemented and uncemented cups implanted during 1991–2001 using either all revisions, or aseptic loosening as the end point.

### 9.1.4.5 Cup design concepts (I and III)

#### 9.1.4.5.1 Whole study period (I and III)

In young patients with primary OA (I), only press-fit porous- and HA-coated uncemented cups showed >95% survival rates at 7 year follow-up with aseptic loosening as the end point (Table 16). At 10 years, only porous-coated uncemented cups had >90% survival rate. In young patients with RA (III), all cup concepts except smooth-threaded uncemented cups had > 95% survival rates at 7 years (Table 16). However, survival rates of all cup concepts declined below 85% at 15 years. In the Cox regression analysis of patients with primary OA (I), both press-fit uncemented cup concepts had a decreased risk of revision as compared to all-poly cemented cups, whereas smooth-threaded cups had an increased risk of revision (Figure 8 and Table 16). Smooth-threaded cups had a significantly higher risk of revision than all-poly cemented cups in patients with RA (III) (Figure 9 and Table 16).

Using any cup revision as the end point, all cup design concepts except smooth-threaded uncemented cups in young patients with primary OA (I), had >90% survival rates at 7 years (Table 17). However, survival rates for all cup concepts at 10 years had declined <90%. Moreover, smooth-threaded uncemented cups had only a 69% survival rate at 10 years. In young patients with RA (III), only press-fit porous-coated uncemented cups and all-poly cemented cups had

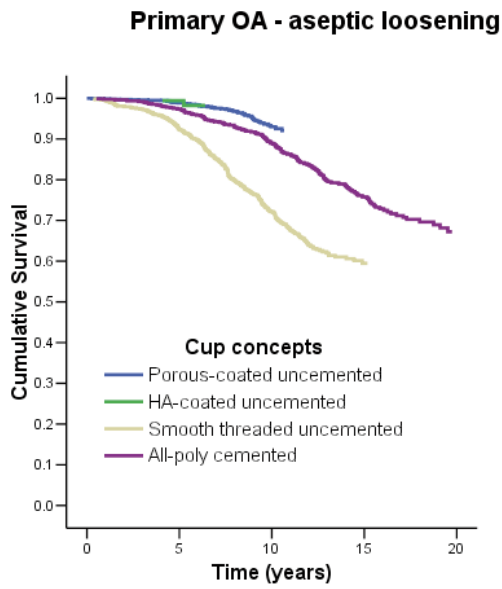



**Fig 8.** Cox-adjusted survival curves of 4217 cups in young patients with primary OA, with cup design concept as the strata factor. The end point defined as cup revision due to aseptic loosening. Adjustment made for age and gender.

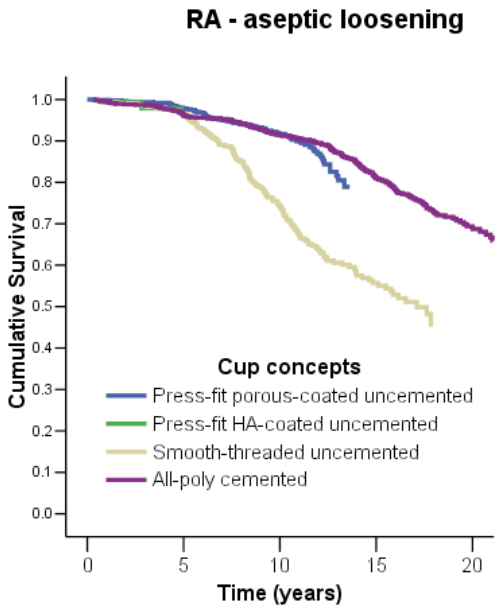



**Fig 9.** Cox-adjusted survival curves of 2151 cups in young patients with RA, with cup design concept as the strata factor. The end point defined as cup revision due to aseptic loosening. Adjustment made for age and gender.

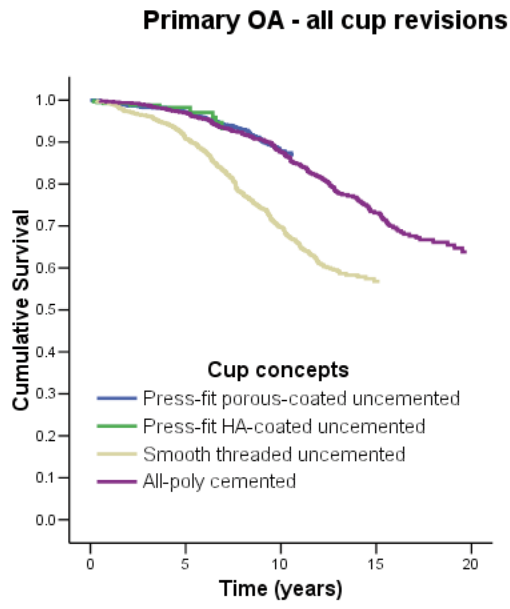



**Fig 10.** Cox-adjusted survival curves of 4217 cups in young patients with primary OA, with cup design concept as the strata factor. The end point defined as any cup revision (including exchange of liner). Adjustment made for age and gender.

>90% survival rates at 7 years (Table 17). The 15-year survival rate for press-fit porous-coated cups declined to <70%. Smooth-threaded uncemented cups had a catastrophic survival rate of only 53% at 15 years. Using the Cox regression analysis smooth-threaded cups had an increased risk of revision as compared to cemented cups in patients with primary OA (I) (Figure 10 and Table 17). All uncemented cup concepts had an increased risk of revision as compared to all-poly cemented cups in patients with RA (III) (Figure 11 and Table 17). Whereas the survival of porous-coated uncemented cups started to decline after 7 years follow-up, the survival of HA-coated uncemented cups was already poorer than that of all-poly cemented cups during the first 7 years of follow-up in patients with RA.

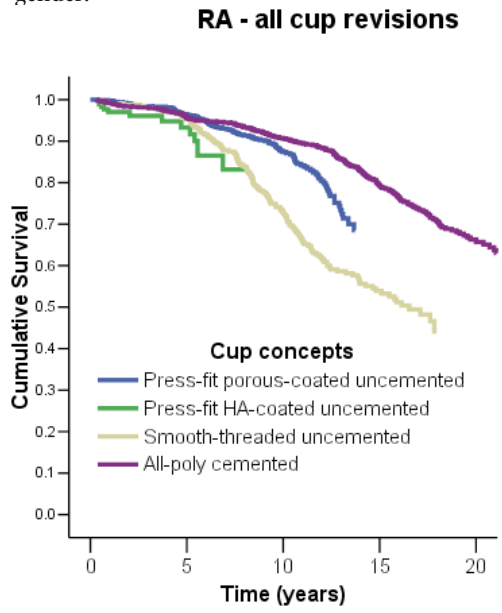



**Fig 11.** Cox-adjusted survival curves of 2151 cups in young patients with RA, with cup design concept as the strata factor. The end point defined as any cup revision (including exchange of liner). Adjustment made for age and gender.

**Table 16.** Survival of cup concepts in young patients with primary OA and RA. Endpoint defined as revision due to aseptic loosening of the cup. 7-, 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| | | | | | | | | | | | Follow-up < 7 yrs | | Follow-up > 7 yrs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cup concept** | **N*** | **MF yr** | **AR 7 yr** | **% 7-year survival (95% CI)** | **AR 10 yr** | **% 10-year survival (95 % CI)** | **AR 15 yr** | **% 15-year survival (95 % CI)** | **Adjusted RR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** |
| *Primary osteoarthritis* | | | | | | | | | | | - | - | - | - |
| Press-fit porous-coated uncemented | 54 / 2194 | 5.6 | 672 | 98 (97 – 99) | 197 | 93 (91 – 95) | - | - | 0.5 (0.3 - 0.7) | <0.001 | - | - | - | - |
| Press-fit HA-coated uncemented | 2 / 571 | 3.3 | 53 | 98 (96 – 100) | 6 | - | - | - | 0.2 (0.0 - 0.7) | 0.02 | - | - | - | - |
| Smooth-threaded uncemented | 208 / 650 | 10.0 | 447 | 85 (82 – 88) | 321 | 71 (68 – 75) | - | - | 2.0 (1.6 - 2.5) | <0.001 | - | - | - | - |
| All-poly cemented | 137 / 802 | 10.7 | 535 | 94 (93 – 96) | 408 | 89 (86 – 91) | - | - | 1.0 | | - | - | - | - |
| *Rheumatoid arthritis* | | | | | | | | | | | | | | |
| Press-fit porous-coated uncemented | 66/770 | 8.5 | 541 | 95 (93 - 97) | 338 | 92 (89 - 94) | 25 | 78 (72 - 85) | 1.0 (0.8 – 1.4) | 0.9 | 1.0 (0.6 – 1.6) | 0.98 | 1.0 (0.7 – 1.5) | 0.93 |
| Press-fit HA-coated uncemented | 2/179 | 4.2 | 39 | 98 (95 – 100) | 12 | - | 0 | - | 0.4 (0.1 – 1.8) | 0.3 | 0.6 (0.1 – 2.3) | 0.4 | - | NA |
| Smooth-threaded uncemented | 121/317 | 10.9 | 258 | 89 (85 - 92) | 189 | 74 (68 - 79) | 96 | 54 (48 - 61) | 2.7 (2.1 – 3.5) | <0.001 | 2.3 (1.4 – 3.8) | 0.001 | 2.9 (2.1 – 3.8) | <0.001 |
| All-poly cemented | 152/885 | 12.3 | 684 | 96 (94 - 97) | 568 | 91 (89 - 94) | 360 | 81 (78 - 85) | 1.0 | - | 1.0 | - | 1.0 | - |

*Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other cup concepts compared to all-poly cemented concept; adjustment made for age and gender). NA = not assigned.

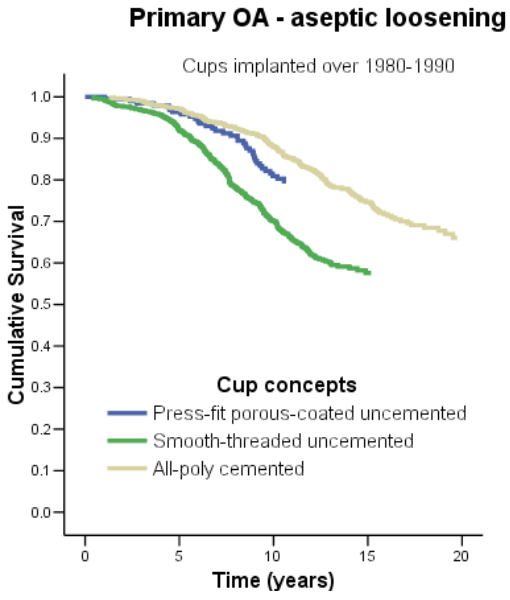
**Table 17.** Survival of cup concepts in young patients with primary OA and RA. Endpoint defined as any cup revision (including exchange of liner). 7-, 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| | | | | | | | | | | | Follow-up < 7 yrs | | Follow-up > 7 yrs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cup concept** | **N*** | **MF yr** | **AR 7 yr** | **% 7-year survival (95% CI)** | **AR 10 yr** | **% 10-year survival (95 % CI)** | **AR 15 yr** | **% 15-year survival (95 % CI)** | **Adjusted RR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** |
| Primary osteoarthritis | | | | | | | | | | | - | - | - | - |
| Press-fit porous-coated uncemented | 114 / 2194 | 5.6 | 673 | 94 (93 – 96) | 197 | 88 (85 – 90) | - | - | 0.8 (0.6 - 1.1) | 0.2 | - | - | - | - |
| Press-fit HA-coated uncemented | 10 / 571 | 3.3 | 54 | 95 (91 – 99) | 6 | - | - | - | 0.7 (0.4 - 1.4) | 0.4 | - | - | - | - |
| Smooth-threaded uncemented | 228 / 650 | 10.0 | 447 | 83 (80 – 86) | 322 | 69 (65 – 73) | - | - | 2.0 (1.6 - 2.4) | <0.001 | - | - | - | - |
| All-poly cemented | 155 / 802 | 10.7 | 536 | 93 (92 - 95) | 409 | 87 (85 – 90) | - | - | 1.0 | | - | - | - | - |
| Rheumatoid arthritis | | | | | | | | | | | | | | |
| Press-fit porous-coated uncemented | 101 / 770 | 8.5 | 542 | 93 (91 - 95) | 340 | 88 (85 - 91) | 25 | 67 (60 - 75) | 1.4 (1.1 – 1.9) | 0.001 | 1.3 (0.8 – 1.9) | 0.3 | 1.5 (1.2 – 1.9) | 0.01 |
| Press-fit HA-coated uncemented | 11 / 179 | 4.2 | 39 | 88 (80 - 95) | 12 | - | 0 | - | 2.5 (1.4 – 4.4)) | 0.003 | 2.7 (1.4 – 5.1) | 0.003 | - | NA |
| Smooth-threaded uncemented | 126 / 317 | 10.9 | 258 | 88 (84 - 92) | 189 | 73 (68 - 78) | 96 | 53 (46 - 59) | 2.6 (2.0 - 3.3) | <0.001 | 2.3 (1.5 – 3.5) | <0.001 | 2.7 (2.0 – 3.6) | <0.001 |
| All-poly cemented | 168 / 885 | 12.3 | 685 | 95 (93 - 96) | 568 | 91 (89 - 93) | 360 | 80 (76 - 83) | 1.0 | - | 1.0 | - | 1.0 | - |

*Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other cup concepts compared to all-poly cemented concept; adjustment made for age and gender). NA = not assigned.

#### 9.1.4.5.2 Primary OA, period 1980–1990 (I)

In patients with primary OA, only press-fit porous-coated uncemented cups had a >90% survival rate at 10 years with revision for aseptic loosening of the cup as the end point (Table 18). However, using the Cox regression analysis, there was not any difference in revision risks between porous-coated uncemented and all-poly cemented cups (Figure 12and Table 18). Smooth-threaded uncemented cups were found to have an increased risk of revision as compared to all-poly cemented cups. With any cup revision as the end point, 10 year survival rates of all concepts except all-poly cemented cups declined to < 85%. Smooth-threaded uncemented cups had a significantly higher risk of revision than all-poly cemented cups as estimated by the Cox regression analysis. In addition, there was a trend for increased risk of revision for press-fit porous-coated uncemented cups as compared to all-poly cemented cups, but the difference was not statistically significant (p=0.07) (Figure 13 and Table 18).



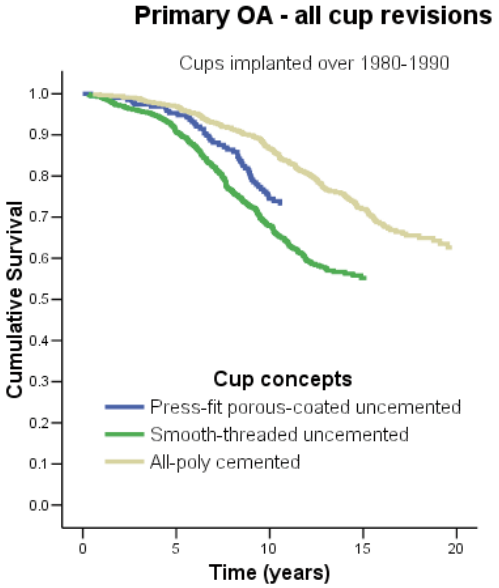




**Fig 13.** Cox-adjusted survival curves calculated for 1262 cups implanted in young patients with primary OA over 1980-1990, with cup design concept as the strata factor. The end point defined as any cup revision (including exchange of liner). Adjustment made for age and gender.

#### 9.1.4.5.3 Primary OA, period 1991–2001 (I)

Only press-fit porous-coated uncemented cups had >95% survival rate at 10 years when revision for aseptic loosening of the cup was taken as the end point for patients with primary OA (Table 18). Using the Cox regression analysis, press-fit porous-coated cups had a decreased risk of revision as compared to all-poly cemented cups (Figure 14 and Table 18). Furthermore, there was a trend towards a decreased risk of revision for press-fit HA-coated uncemented cups as compared to all-poly cemented

**Fig 12.** Cox-adjusted survival curves calculated for 1262 cups implanted in young patients with primary OA over 1980-1990, with cup design concept as the strata factor. The end point defined as revision due to aseptic loosening of the cup. Adjustment made for age and gender.

cups, but the difference lacked statistical significance (p=0.07). With any cup revision taken as the end point, the 10 year survival rates of press-fit porous-coated uncemented cups and all-poly cemented cups were still >90%. Using the Cox regression analysis, no differences were found for risk of revision between uncemented and all-poly cemented cup concepts (Figure 15 and Table 18).

#### 9.1.4.5.4 Cohort effect among cup design concepts (I and III)

The Cox regression analysis indicated that press-fit porous-coated uncemented cups implanted into patients with primary OA (I) during 1991–2001 had significantly lower risk of revision than cups of the same design concept implanted during the first decade (1980–1990) of the study period when

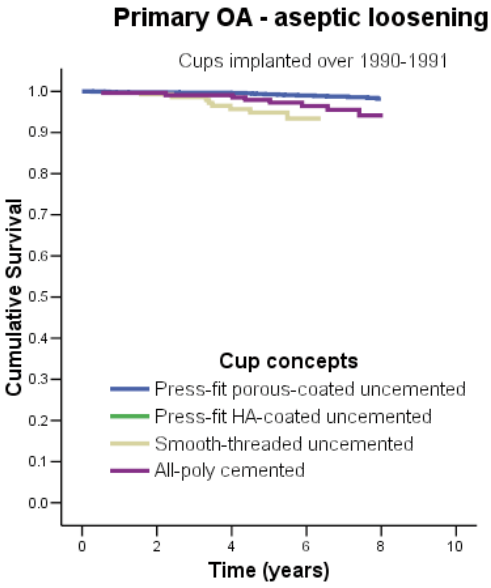



**Fig 14.** Cox-adjusted survival curves calculated for 2946 cups implanted in young patients with primary OA over 1991-2001, with cup design concept as the strata factor. The end point defined as revision due to aseptic loosening of the cup. Adjustment made for age and gender.

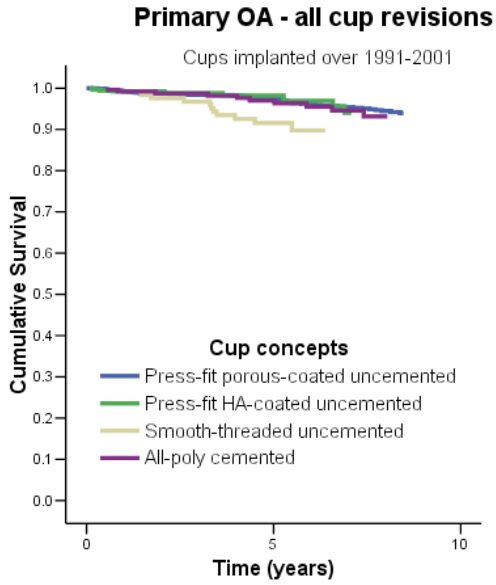



**Fig 15.** Cox-adjusted survival curves calculated for 2946 cups implanted in young patients with primary OA over 1991-2001, with cup design concept as the strata factor. The end point defined as any cup revision (including exchange of liner). Adjustment made for age and gender.

either all revisions or aseptic loosening was taken as the end point (p<0.001 for both comparisons; Table 18). The cohort effect was also apparent for smooth threaded uncemented cups. Such cups implanted during the 1991–2001 period had a significantly lower risk of revision than the same type of cups implanted during 1980–1990 (all revisions, p=0.02; aseptic loosening, p=0.003; Table 18). There was no difference in survival rates for all-poly cemented cups between the cohorts of 1980–1990 and 1991–2001. Cox regression analysis of patients with RA (III), revealed that press-fit porous-coated uncemented cups implanted during 1992–2003 had a significantly decreased risk of revision as compared to cups of the same concept implanted during 1980–1991 with either aseptic loosening (p<0.001) or all revisions (p=0.03) as the end point.

**Table 18.** Survival of cup concepts in young patients with primary osteoarthritis in two time periods. 7- and 10-year survival rates obtained from the Kaplan-Meier analysis.

| | | All revisions | | | | *Aseptic loosening* | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Cup concept** | **N** | **% 7-year survival (95% CI)** | **% 10-year survival (95% CI)** | **ARR (95 % CI)** | **p** | **% 7-year survival (95% CI)** | **% 10-year survival (95% CI)** | **ARR (95 % CI)** | **p** |
| *1980-1990* | | | | | | | | | |
| Press-fit porous-coated uncemented | 195 | 89 (84 – 93) | 74 (68 – 81) | 1.4 (1.0 – 1.9) | 0.06 | 96 (93 – 98) | 92 (88 – 95) | 1.1 (0.8 – 1.7) | 0.5 |
| Smooth-threaded uncemented | 533 | 82 (79 – 85) | 68 (64 – 72) | 1.9 (1.5 – 2.4) | <0.001 | 84 (80 – 87) | 70 (66 – 74) | 2.0 (1.6 – 2.5) | <0.001 |
| All-poly cemented | 534 | 93 (91 – 95) | 87 (84 – 90) | 1.0 | - | 94 (92 – 96) | 88 (85 – 91) | 1.0 | - |
| *1991-2001* | | | | | | | | | |
| Press-fit porous-coated uncemented | 1999 | 95 (94 – 97) | 94 (92 – 96) | 0.9 (0.5 – 1.9) | 0.9 | 99 (98 – 993) | 98 (97 – 99) | 0.3 (0.1 – 0.8) | 0.01 |
| Press-fit HA-coated uncemented | 562 | 96 (92 – 100) | - | 0.9 (0.3 – 2.2) | 0.8 | 99 (98 – 100) | - | 0.1 (0.0 – 1.2) | 0.07 |
| Smooth-threaded uncemented | 117 | 89 (83 – 96) | 89 (83 – 96) | 1.7 (0.7 – 4.1) | 0.2 | 92 (86 – 98) | 92 (86 – 98) | 1.4 (0.5 – 3.9) | 0.5 |
| All-poly cemented | 268 | 95 (91 – 98) | 93 (89 – 98) | 1.0 | - | 95 (92 – 99) | 94 (89 – 98) | 1.0 | - |

N = number of primary operations. ARR = Adjusted risk ratio from the Cox regression analysis (other cup concepts compared to the all-poly cemented concept; adjustment made for age and gender). During 1980-1990, only 9 HA-coated uncemented cups were implanted; they were not included in the analysis.

### 9.1.4.6 Uncemented cup designs (II)

Only three of the nine uncemented cup designs studied (the ABG I, the Biomet Universal and the Harris-Galante II) had >90% survival rates at 10 years in young patients with primary OA, when aseptic loosening was taken as the end point (Table 19). Survival rates of the Biomet Universal and the Harris-Galante II cups remained at around 90%, even at 13 years follow-up. The most recently introduced uncemented cup designs had good survival rates at five years, but 10 year survival data are still not yet available for these designs. However, there was no difference between survival rates of these new designs and the reference cup (Biomet Universal) at five years. The Biomet Romanus (p=0.009) and the PCA Pegged (p<0.001) cups had a significantly higher risk of revision than the Biomet Universal cup after five years of follow-up using the Cox regression analysis (Figure 16 and Table 19). There were no other differences in survival rates between the cup designs.

With any cup revision taken as the end point, only the Harris-Galante II cup had over 80% survival rate at 10 years (Table 19). The 13 year survival rates of cups with long-term follow-up (the Biomet Universal, the Harris-Galante II and the PCA Pegged) declined to <80%. The ABG I (RR 0.3, 95% CI 0.1–0.8; p=0.02) and the ABG II cups (RR 0.2, 95% CI 0.0 - 0.7; p=0.02) had a lower risk of revision than the Biomet Universal cup before five years of follow-up had elapsed, when analysed by the Cox regression method (Figure 17 and Table 19). However, the difference between the ABG I and the Biomet Universal cups disappeared after 5 years of follow-up. The Harris-Galante II cup was found to have a 0.7-fold (95% CI 0.5–1.0; p=0.04) decreased risk of revision as compared to the Biomet Universal cup. The Biomet Romanus cup had a 1.9-fold (95% CI 1.3–2.7; p<0.001) increased risk of revision as compared to the reference cup (Biomet Universal).

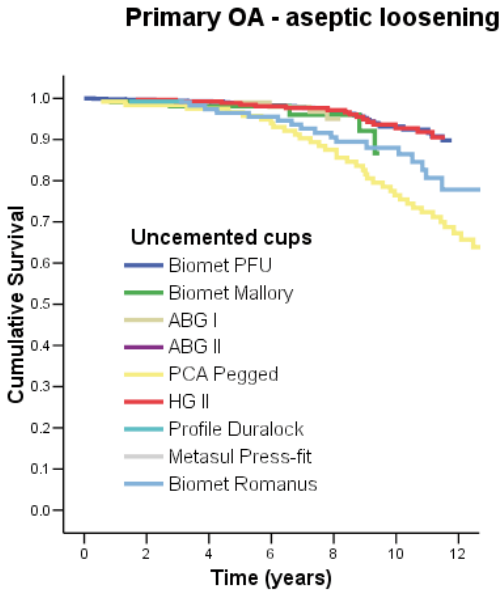



**Fig 16.** Cox-adjusted survival curves calculated for 2801 cups, with cup design as the strata factor. The end point defined as revision due to aseptic loosening of the cup. Adjustment made for age and gender. Curve of the Biomet Vision cup is not shown as it had a 100% survival rate at 5 years.

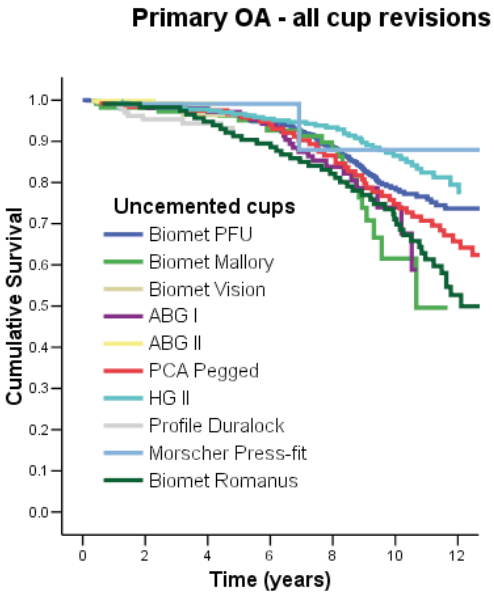



**Fig 17.** Cox-adjusted survival curves calculated for 2801 cups, with cup design as the strata factor. The end point defined as any cup revision. Adjustment made for age and gender. Curves of the ABG II and the Biomet Vision cups are not shown as they had a 100% survival rate.

**Table 19.** Survival and adjusted risk ratio for revision of uncemented cup designs. Endpoint was defined as revision due to aseptic loosening of the cup or cup revision for any reason. 7- 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| | | | | | | | | | | Follow-up < 7 yrs | | Follow-up > 7 yrs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cup design** | **N*** | **MF yr** | **AR 7 yr** | **% 7-year survival (95% CI)** | **AR 10 yr** | **% 10-year survival (95 % CI)** | **AR 15 yr** | **% 15-year survival (95 % CI)** | **Adjusted RR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** | **ARR (95 % CI)** | **p** |
| *Aseptic loosening* | | | | | | | | | | | - | - | - | - |
| ABG I | 4 / 108 | 8.2 | 102 | 99 (97 - 100) | 28 | 95 (90 – 100) | 0 | - | 0.6 (0.2 - 1.7) | 0.4 | 0.5 (0.1 - 2.2) | 0.3 | 0.8 (0.2 - 2.7) | 0.7 |
| ABG II | 1 / 473 | 3.3 | 135 | 99 (98 - 100) | 0 | - | 0 | - | 0.3 (0.0 - 2.3) | 0.2 | 0.3 (0.0 - 2.6) | 0.3 | - | NA |
| Biomet Mallory | 5 / 110 | 7.5 | 98 | 98 (95 – 100) | 20 | 87 (73 – 100) | 0 | - | 1.3 (0.5 - 3.3) | 0.6 | 1.5 (0.3 - 6.7) | 0.6 | 1.1 (0.3 - 3.8) | 0.8 |
| Biomet Romanus | 18 / 114 | 9.6 | 107 | 96 (93 – 100) | 66 | 88 (81 – 94) | 17 | - | 2.5 (1.4 - 4.6) | 0.002 | 2.8 (0.9 - 9.1) | 0.08 | 2.5 (1.3 - 4.8) | 0.009 |
| Biomet Universal | 34 / 898 | 7.3 | 724 | 99 (98 – 100) | 217 | 93 (91 – 96) | 58 | 90 (86 – 94) | 1.0 | - | 1.0 | - | 1.0 | - |
| Biomet Vision | 0 / 418 | 2.6 | 59 | 100 | 0 | - | 0 | - | - | NA | - | NA | - | NA |
| Harris-Galante II | 16 / 277 | 9.3 | 255 | 99 (98 - 100) | 139 | 94 (90 – 97) | 33 | 91 (86 – 95) | 1.0 (0.5 - 1.7) | 0.9 | 0.9 (0.2 - 3.2) | 0.8 | 1.0 (0.5 - 1.9) | 0.9 |
| Morscher Press-Fit | 2 / 136 | 3.4 | 23 | 100 | 17 | - | 11 | - | 0.8 (0.2 - 3.5) | 0.8 | - | NA | 1.1 (0.3 - 4.9) | 0.9 |
| PCA Pegged | 37 / 122 | 10.6 | 113 | 97 (93 – 100) | 82 | 76 (68 – 85) | 40 | 64 (54 – 74 | 3.9 (2.4 - 6.3) | < 0.001 | 2.7 (0.8 - 8.5) | 0.1 | 4.2 (2.4 - 7.3) | <0.001 |
| Profile Duraloc | 1 / 145 | 5.5 | 90 | 99 (98 - 100) | 14 | - | 0 | - | 0.3 (0.0 - 2.2) | 0.2 | 0.7 (0.1 - 5.6) | 0.7 | - | NA |
| *Any stem revision* | | | | | | | | | | | | | | |
| ABG I | 22 / 108 | 8.2 | 102 | 97 (94 - 100) | 28 | 79 (70 – 88) | 0 | - | 0.9 (0.6 - 1.4) | 0.6 | 0.3 (0.1 - 0.8) | 0.02 | 1.4 (0.8 - 2.2) | 0.2 |
| ABG II | 2 / 473 | 3.3 | 135 | 99 (98 - 100) | 0 | - | 0 | - | 0.2 (0.0 - 0.6) | 0.009 | 0.2 (0.0 - 0.7) | 0.02 | - | NA |
| Biomet Mallory | 21 / 110 | 7.5 | 99 | 96 (93 – 100) | 21 | 61 (45 – 78) | 0 | - | 1.5 (0.9 - 2.4) | 0.08 | 1.0 (0.4 - 2.8) | 1.0 | 1.7 (1.0 - 2.9) | 0.04 |
| Biomet Romanus | 44 / 114 | 9.6 | 108 | 91 (86 – 96) | 68 | 71 (62 – 80) | 17 | - | 1.9 (1.3 - 2.7) | <0.001 | 2.4 (1.2 - 5.0) | 0.02 | 1.8 (1.2 - 2.7) | 0.06 |
| Biomet Universal | 114 / 898 | 7.3 | 726 | 96 (95 – 98) | 223 | 79 (75 – 83) | 58 | 74 (69 – 79) | 1.0 | - | 1.0 | - | 1.0 | - |
| Biomet Vision | 4 / 418 | 2.6 | 59 | 99 (98 - 100) | 0 | - | 0 | - | 0.5 (0.2 - 1.3) | 0.2 | 0.5 (0.2 - 1.4) | 0.2 | - | NA |
| Harris-Galante II | 37 / 277 | 9.3 | 255 | 97 (94 – 99) | 141 | 87 (83 - 92) | 33 | 78 (70 – 85) | 0.7 (0.5 - 1.0) | 0.04 | 0.9 (0.4 - 1.9) | 0.7 | 0.6 (0.4 - 1.0) | 0.03 |
| Morscher Press-Fit | 3 / 136 | 3.4 | 23 | 99 (97 - 100) | 17 | - | 11 | - | 0.4 (0.1 - 1.3) | 0.1 | 0.4 (0.1 - 2.9) | 0.4 | 0.4 (0.1 - 1.6) | 0.2 |
| PCA Pegged | 39 / 122 | 10.6 | 113 | 97 (93 – 100) | 82 | 75 (67 – 83) | 41 | 63 (53 – 73) | 1.3 (0.9 - 1.9) | 0.2 | 0.9 (0.3 - 2.5) | 0.8 | 1.4 (0.9 - 2.1) | 0.1 |
| Profile Duraloc | 8 / 145 | 5.5 | 91 | 93 (89 - 98) | 14 | - | 0 | - | 0.7 (0.3 - 1.4) | 0.3 | 1.8 (0.8 - 3.8) | 0.2 | - | NA |

*Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other stem designs compared to the Biomet Universal cup; adjustment made for age and gender).

### 9.1.4.7 Total hip replacement designs (II)

The Biomet Bi-Metric – Universal (the reference design), the ABG I – ABG I and the Anatomic Mesh – Harris-Galante (HG) II cup-stem combinations all had >95% survival rates at 10 years with aseptic loosening of the stem and/or the cup as the end point in young patients with primary OA (Table 20). The Cox regression analysis revealed, that the Bi-Metric – Romanus and the PCA Std – PCA Pegged prostheses had significantly higher risk of revision than the Bi-Metric – Universal combination (Figure 18 and Table 20).

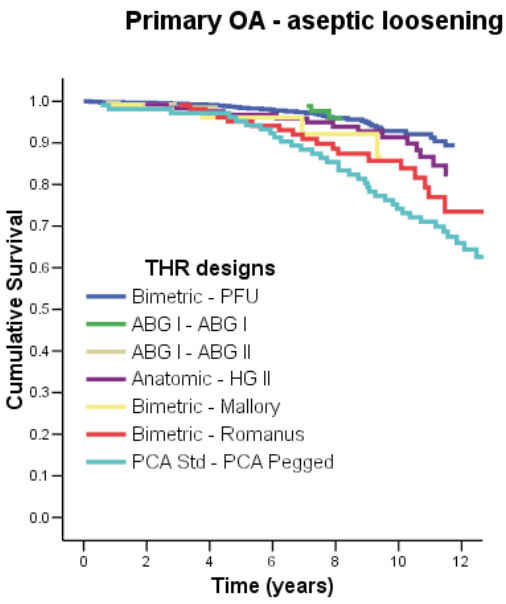



**Fig 18.** Cox-adjusted survival curves calculated for 2061 THRs, with THR design as the strata factor. The end point defined as revision due to aseptic loosening of the stem and/or the cup. Adjustment made for age and gender. The curve of the Bi-Metric – Vision THR is not shown as it had a 100% survival rate at 5 years.

When the end point was defined as any cup and/or stem revision, survival rates of most designs declined markedly. Only the Anatomic Mesh – HG II prosthesis had >80% survival rate at 10 years (Table 20). The Bi-Metric – Romanus prosthesis had an increased risk of revision as compared to the reference brand (the Bi-Metric – Universal prosthesis) when analysed by the Cox regression method (Figure 19 and Table 20). The ABG I – ABG II combination had a lower risk of revision than the reference design.

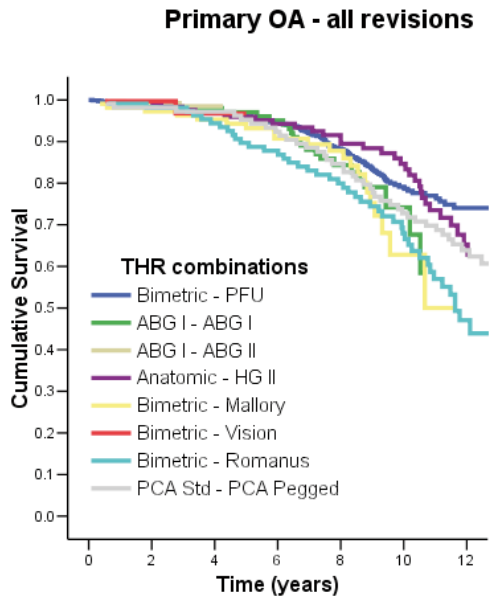



**Fig 19.** Cox-adjusted survival curves calculated for 2061 THRs, with THR design as the strata factor. The end point defined as any revision. Adjustment made for age and gender.

**Table 20.** Survival and adjusted risk ratio for revision of uncemented THR designs. Endpoint was defined as revision due to aseptic loosening of the stem and/or the cup or revision for any reason. 7- 10-, and 15-year survival rates obtained from the Kaplan-Meier analysis.

| THR design | N* | MF yr | AR 7 yr | % 7-year survival (95 % CI) | AR 10 yr | % 10-year survival (95 % CI) | AR 15 yr | % 15-year survival (95 % CI) | Adjusted RR for revision (95 % CI) | p |
|---|---|---|---|---|---|---|---|---|---|---|
| Aseptic loosening | | | | | | | | | | |
| ABG I - ABG I | 3 / 105 | 8.2 | 99 | 100 | 27 | 96 (91 - 100) | 0 | - | 0.6 (0.2 - 1.9) | 0.4 |
| ABG I - ABG II | 3 / 266 | 4.3 | 122 | 99 (97 - 100) | 0 | - | 0 | - | 0.9 (0.3 - 3.2) | 0.9 |
| Anatomic Mesh - HG II | 14 / 127 | 9.7 | 120 | 98 (95 - 100) | 75 | 93 (88 – 98) | 20 | 82 (73 - 92) | 1.6 (0.8 - 3.0) | 0.2 |
| Bi-Metric - Mallory | 6 / 107 | 7.5 | 95 | 96 (92 - 100) | 20 | 87 (74 – 100) | 0 | - | 1.4 (0.6 - 3.4) | 0.4 |
| Bi-Metric - Universal | 36 / 858 | 7.4 | 706 | 99 (98 – 99) | 216 | 93 (90 – 96) | 57 | 89 (85 – 94) | 1.0 | - |
| Bi-Metric - Vision | 0 / 385 | 2.6 | 55 | 100 | 0 | - | 0 | - | - | NA |
| Bi-Metric - Romanus | 19 / 106 | 9.4 | 99 | 95 (91 – 99) | 58 | 86 (78 – 93) | 15 | - | 2.8 (1.6 - 4.9) | < 0.001 |
| PCA Std - PCA Pegged | 37 / 107 | 11.1 | 101 | 95 (91 - 99) | 78 | 74 (66 – 83) | 40 | 63 (52 - 73) | 4.0 (2.5 - 6.5) | < 0.001 |
| Any revision | | | | | | | | | | |
| ABG I - ABG I | 21 / 105 | 8.2 | 99 | 98 (95 - 100) | 27 | 79 (70 - 88) | 0 | - | 1.3 (0.8 - 2.1) | 0.3 |
| ABG I - ABG II | 3 / 266 | 4.3 | 122 | 99 (97 - 100) | 0 | - | 0 | - | 0.3 (0.1 - 1.0) | 0.04 |
| Anatomic Mesh - HG II | 29 / 127 | 9.7 | 120 | 97 (94 – 100) | 76 | 86 (80 – 93) | 20 | 63 (51 - 75) | 1.0 (0.7 - 1.6) | 0.9 |
| Bi-Metric - Mallory | 21 / 107 | 7.5 | 96 | 94 (90 – 99) | 21 | 62 (46 – 79) | 2 | - | 1.5 (1.0 - 2.5) | 0.07 |
| Bi-Metric - Universal | 112 / 858 | 7.4 | 707 | 96 (95 – 98) | 220 | 79 (75 – 83) | 57 | 74 (69 - 79) | 1.0 | |
| Bi-Metric - Vision | 2 / 385 | 2.6 | 55 | 100 (99 - 100) | 0 | - | 0 | - | 0.3 (0.1 - 1.1) | 0.06 |
| Bi-Metric - Romanus | 45 / 106 | 9.4 | 101 | 90 (84 – 95) | 60 | 68 (58 - 77) | 15 | - | 2.2 (1.5 - 3.1) | < 0.001 |
| PCA Std - PCA Pegged | 40 / 107 | 11.1 | 101 | 95 (91 - 99) | 78 | 72 (64 – 81) | 40 | 60 (50 - 70) | 1.4 (1.0 - 2.1) | 0.06 |

*Number of revisions / number of total operations. MF = mean follow-up (years). AR = at risk. RR = risk ratio from the Cox regression analysis (other implant designs compared to the Bi-Metric / Universal THR; adjustment made for age and gender). NA = not assigned.

### 9.1.4.8 Gender and age as risk factors (I and III)

#### 9.1.4.8.1 Primary osteoarthritis (I)

Cox regression analysis of the total data revealed that in young patients with primary OA, females had a higher risk of revision than males with either all revisions (RR 1.2, 95% CI 1.0–1.4; p=0.02) or aseptic loosening (RR 1.2, 95% CI 1.0–1.4; p=0.02) as the end point. When the risk of stem revision was analyzed using the Cox regression method, there was no significant difference in risk of revision between the genders when either all revisions or aseptic loosening was used as the end point. However, females had a higher risk of cup revision than males when either all revisions (RR 1.2, 95% CI 1.1–1.5; p=0.01) or aseptic loosening (RR 1.3, 95% CI 1.1–1.5; p=0.009) was chosen as the end point. Results were similar after adjustment for age and cup design concepts.

With any revision as the end point, younger patients (<46 years) were found to have a 1.2-fold (95% CI 1.0–1.5; p=0.03) increased risk of revision as compared to older patients (46–54 years). However, after adjustment for gender and implant concepts the difference disappeared. With aseptic loosening as the end point, the risk of revision in the younger age group (<46 years) was 1.3 (95% CI 1.1–1.6; p=0.005) times as high as that in the older age group (46–54 years). Adjustment for gender and implant concepts using the Cox regression method gave similar results. When the risk of stem revision was analyzed there was no difference in risk of revision between the age groups with either all revisions or aseptic loosening as the end point (with or without adjustment for gender and stem concepts). However, the younger age group had a higher risk of cup revision than the older age group when either all revisions (RR 1.2, 95% CI 1.1–1.5; p=0.01) or aseptic loosening (RR 1.3, 95% CI 1.1–1.5; p=0.009) served as the end point. Adjustment for gender and cup design concepts in the Cox model gave similar results.

#### 9.1.4.8.2 Rheumatoid arthritis (III)

The Cox regression analysis of the total data did not reveal any difference in risk of revision between the genders of young patients with RA when either all revisions or aseptic loosening was taken as the end point (with or without adjustment for age and implant concepts). When the risk of stem revision was analyzed using the Cox regression method, there was a trend towards a greater risk of stem revision in males as compared to females with adjustment for age and stem concepts (aseptic loosening, p=0.06; any stem revision, p=0.05). Analysis of cup revisions suggested that there was no difference in risk of revision between the genders when either all cup revisions or aseptic loosening served as the end point (with or without adjustment for age and cup design concepts).

With aseptic loosening taken as the end point, there was no difference in revision risk between the age groups (with or without adjustment for gender and stem concepts). With any revision as the end point, younger patients (<46 years) were found to have a 1.2-fold (95% CI 1.0–1.5; p=0.03) increased risk of revision as compared to older patients (46–54 years) (with adjustment for gender and implant design concepts). When the risk of stem revision was analyzed by the Cox model, there was no significant difference in risk of revision between the age groups using either all revisions or aseptic loosening as the end point (with or without

adjustment for gender and stem design concepts). However, the younger age group had a higher risk of cup revision than the older age group when either all revisions (RR 1.3, 95% CI 1.1–1.6; p=0.005) or aseptic loosening (RR 1.3, 95% CI 1.1–1.7; p=0.008) was chosen as the end point (with adjustment for gender and cup design concepts).

#### 9.1.4.9 Hospital volume and survival of implants (I)

Neither the Kaplan-Meier analysis nor the Cox multiple-regression model found any difference in risk of revision between hospitals performing more than 10 and those performing 10 or fewer THAs annually in young patients with primary OA irrespective of whether the end point was defined as revision due to any reason or as aseptic loosening.

## 9.2 Clinical studies (IV and V)

### 9.2.1 Clinical results

#### 9.2.1.1 Functional results

##### 9.2.1.1.1 Patients with high congenital dislocation (IV)

The Harris hip score (HHS) averaged 54.2 points (range, 13– 85) preoperatively, 86.5 points (range, 48–100 ) at the one-year follow-up examination, and 83.9 points (range, 34–100 ) at the final follow-up evaluation (p<0.001 for both comparisons). The mean HHS for hip pain increased from 22.1 points (range, 0–40) preoperatively to 41.5 points (range, 0–44) at the one-year follow-up evaluation (p<0.001). At the time of final follow-up, 45 of the 68 hips (66%) (37 patients) were totally pain-free. Pain was slight, occasional in 16 hips (24%), mild in three, moderate in one, marked in three, and for one hip there was severe rest pain. The patient with severe rest pain had a completely worn liner in the painful hip at the time of the last follow-up; only three weeks earlier the hip had been painless; the patient was urgently scheduled for a liner revision. In total, 43 (67%) of 64 hips (33 of 52 patients) had a good or excellent HHS (>80 points). In all, 44 of the 56 patients (79%) subjectively reported good satisfaction at their last follow-up visit, seven patients (12%) were unsatisfied with the outcome, and five patients had no opinion on the outcome.

All patients had a limp preoperatively, and the Trendelenburg sign was positive in 57 (84%) of the 68 hips (Table 5). At the time of final follow-up, there was a positive Trendelenburg sign in only five of the 64 hips (78%). In 59 (92%) of 64 hips, the abduction strength of the hip was graded as good or slightly decreased (Seddon 1954) (Table 21). Elements of the HHS for function are summarized in Table 22. A total of 32 (57%) patients were able to walk without a limp; 17 (53%) had an unlimited walking distance. Moreover, 31 (55%) patients were able to walk without support; 23 had an unlimited walking distance. Nine patients used a single cane for long walks, eight patients used a single cane most of the time, five patients used two canes, and three patients used two crutches. A total of 24 (43%) patients had a limp, which was moderate in four and slight in 20 (compare abduction strength). The median distance that the patient could walk increased from 100–500 meters to 1000–1500 meters (p<0.001). In all, 26 (46%) patients were able to walk an

unlimited distance at the time of their last follow-up visit. The range of motion increased significantly in extension and flexion, abduction, and internal rotation after THA, as did the mean HHS for the range of motion (Table 23).

**Table 21.** Abduction strength of the hips at final follow-up.

| Abduction strength | N (%) | Active ROM* | Trendelenburg (+/-) |
|---|---|---|---|
| Active contraction without movement (1) | 1 (2%) | 0 | 1 / 0 |
| Active movement against gravity (no resistance from physician) (3) | 4 (6%) | 4 +/- 8 | 2 / 2 |
| Active movement against gravity and resistance (4) | 21 (33%) | 25 +/- 10 | 2 / 19 |
| Normal strength (5) | 38 (59%) | 36 +/- 9 | 0 / 38 |

*The values are given, in degrees, as the mean and standard deviation. The abduction strength was graded from zero (no active contraction) to five (normal strength) according to MRC scale.

**Table 22.** Harris Hip Score for function* at final follow-up.

| Elements | Preoperative | At final follow-up | p-value |
|---|---|---|---|
| Limp | 1.2 (0 - 5) | 8.3 (0 - 11) | <0.001 |
| Support | 8.2 (0 - 11) | 8.1 (0 - 11) | 0.74 |
| Walking distance | 6.2 (2 - 11) | 8.3 (2 - 11) | <0.001 |
| Stairs | 1.7 (0 - 4) | 2.3 (1 - 4) | 0.004 |
| Shoes and socks | 2.4 (0 - 4) | 2.8 (0 - 4) | 0.11 |

*The values are given as the mean (range).

**Table 23.** Range of Motion *

| Movement | Preoperative | Final Follow-Up | P-value |
|---|---|---|---|
| Extension | 2 +/- 8 | 8 +/- 6 | <0.001 |
| Flexion | 95 +/- 24 | 106 +/- 10 | <0.001 |
| Abduction | 31 +/- 15 | 38 +/- 10 | 0.001 |
| Adduction | 26 +/- 13 | 27 +/- 7 | 0.35 |
| Internal Rotation | 33 +/- 23 | 40 +/- 17 | 0.026 |
| External Rotation | 38 +/- 26 | 35 +/- 16 | 0.58 |
| *HHS for range of motion* | *4.5 (1.0 - 5.0)* | *4.9 (4.6 - 5.0)* | *<0.001* |
| *HHS for absence of deformity* | *1.9 (0 - 4)* | *3.9 (0 - 4)* | *<0.001* |

* The values are given, in degrees, as the mean and standard deviation.

The mean functional leg-length discrepancy decreased from 3.5 cm (range, 0–10.0 cm) before surgery to 1.2 cm (range, 0–6.0 cm) at the time of the final follow-up evaluation ($p<0.001$).

A total of 29 of the 68 hips (43%, in 25 patients) required revision during the follow-up period. With revision for any reason as the end point, the survival rate was 73% (95% CI 63–84) at 10 years.

#### 9.2.1.1.2 Patients with a previous Schanz osteotomy of the femur (V)

The HHS averaged 52.3 points (range, 13–85) preoperatively, 86.7 points (range, 63–100) at the one-year follow-up examination, and 88.8 points (range, 49–100) at the final follow-up evaluation ($p<0.001$ for both comparisons with the preoperative value). The mean HHS for hip pain increased from 20.2 points (range, 0–40) preoperatively to 42.1 points (range, 0–44) at the one-year follow-up ($p<0.001$). Of the 68 hips, 51 (75%) in 44 patients were totally pain-free at the time of final follow-up. Pain was slight and occasional in 13 hips (19%), mild in two, and marked in two. One patient with marked pain in the hip had undergone two cup-revisions in another hospital, and after the last revision she had had persistent neuropathic pain in the lower limb. The other patient with marked pain had undergone a liner revision in another hospital five months earlier, and still had marked pain in the hip. As many as 55 (82%) of the 67 hips (46 of the 58 patients) who were examined by us at the time of final follow-up) had a good or excellent HHS (>80 points). Forty-five (76%) of the 59 patients subjectively reported good satisfaction at the time of the last follow-up visit, seven patients had no opinion on outcome, and seven patients (12%) were dissatisfied with the outcome.

Preoperatively, all patients had a limp and the Trendelenburg sign was positive in 52 (76%) of the 68 hips (Table 5). At the time of final follow-up, there was a positive Trendelenburg sign in only five (8%) of the 59 hips operated with shortening osteotomy and distal advancement of the greater trochanter, and in two of the eight hips treated with segmental shortening and angular correction ($p=0.21$). The abduction strength of 59 (88%) of the 67 hips was graded as good or slightly decreased (Seddon 1954) (Table 24). Elements of the HHS for function are summarized in Table 25. There was a trend towards a better HHS for limp in patients treated with distal advancement of the greater trochanter than in patients operated on with segmental shortening with angular correction. However, the difference was on the borderline of being statistically significant (9.3 vs. 6.8 points, $p=0.05$).

**Table 24.** Abduction strength of the hips at final follow-up.

| Abduction strength | N (%) | Active abduction | Trendelenburg (+/-) |
|---|---|---|---|
| No active contraction (0) | 1 (1%) | 0 | 1 / 0 |
| Active contraction without movement (1) | 3 (4%) | 0 | 3 / 0 |
| Active movement against gravity (no resistance from physician) (3) | 4 (6%) | 8 +/- 8 | 3 / 1 |
| Active movement against gravity and resistance (4) | 17 (25%) | 21 +/- 10 | 0 / 17 |
| Normal strength (5) | 42 (63%) | 33 +/- 9 | 0 / 42 |

*The values are given, in degrees, as the mean and standard deviation. The abduction strength was graded from zero (no active contraction) to five (normal strength) according to MRC scale.

**Table 25.** Harris Hip Score for function* at final follow-up.

| Elements | Preoperative | At final follow-up | p-value |
|---|---|---|---|
| Limp | 1.4 (0 – 11) | 8.8 (0 - 11) | <0.001 |
| Support | 8.6 (2 - 11) | 9.0 (0 - 11) | 0.41 |
| Walking distance | 6.3 (2 - 11) | 9.0 (2 - 11) | <0.001 |
| Stairs | 1.9 (1 - 4) | 2.5 (1 - 4) | 0.003 |
| Shoes and socks | 2.3 (0 - 4) | 3.2 (0 - 4) | 0.008 |

*The values are given as the mean (range).

A total of 24 (43%) patients were able to walk without a limp, and 22 (88%) of them were able to walk an unlimited distance. In total, 23 (50%) of the 46 patients treated with distal advancement of the greater trochanter and six of the eight patients treated with segmental shortening osteotomy had a limp (p=0.26). As many as 38 patients (64%) were able to walk without support, and 32 (84%) of them were able to walk an unlimited distance. Nine patients used a single cane for long walks, six patients used a single cane most of the time, five patients used two canes, and one patient used two crutches. As many as 34 (57%) patients had a limp, which was severe in six and slight in 28 cases. (Compare abduction strength). The median distance that the patients could walk increased from two to three blocks preoperatively to unlimited walking distance at the time of follow-up (p< 0.001). As many as 35 (59%) patients could walk an unlimited distance at the time of their last follow-up visit.

The range of motion increased significantly in extension and flexion, abduction, and internal rotation after THA, as did the mean HHS for range of motion and for absence of deformity (Table 26). Patients who had been treated with distal advancement of the greater trochanter had significantly better extension than those patients who had undergone a segmental shortening osteotomy with angular correction (9° vs. 4°, p=0.03). There were no other significant differences in the range of movements between these two groups.

**Table 26.** Range of Motion *

| Movement | Preoperative | Final Follow-Up | P-value |
|---|---|---|---|
| Extension | 2 +/- 9 | 8 +/- 6 | <0.001 |
| Flexion | 83 +/- 29 | 104 +/- 11 | <0.001 |
| Abduction | 27 +/- 17 | 39 +/- 11 | 0.001 |
| Adduction | 23 +/- 14 | 24 +/- 8 | 0.55 |
| Internal Rotation | 26 +/- 29 | 41 +/- 18 | 0.01 |
| External Rotation | 32 +/- 30 | 34 +/- 18 | 0.80 |
| *HHS for range of motion* | *4.1 (1.1 - 5.0)* | *4.9 (4.1 - 5.0)* | *<0.001* |
| *HHS for absence of deformity* | *1.7 (0 - 4)* | *3.8 (0 - 4)* | *<0.001* |

* The values are given, in degrees, as the mean and standard deviation.

The mean functional leg-length discrepancy decreased from 4.6 cm (range, 1.0–10.0 cm) before surgery to 1.9 cm (range, 0–7.0 cm) at the time of the final follow-up ($p< 0.001$). In eight patients (eight hips) with a metaphyseal shortening osteotomy and angular correction, the mean leg-length discrepancy decreased from 5.6 cm (range, 3.0–8.0 cm) preoperatively to 1.8 cm (range, 0–3.0 cm) at the time of final follow-up ($p=0.02$). For those patients with a transposition of the greater trochanter and femoral shortening osteotomy, the corresponding figures were 4.5 cm (1.0–10.0 cm) preoperatively, and 1.9 cm (0–7.0 cm) at the final follow-up ($p<0.001$).

Of the 68 hips, 42 (62%), in 37 patients, required revision during the follow-up period. With revision for any reason being chosen as the end point, the survival rate was 52% (95% CI 40–63) at 10 years.

## 9.2.2 Prosthetic components

### 9.2.2.1 Prosthetic components in patients with high congenital dislocation (IV)

The revision rate of the acetabular component was 44%. Aseptic loosening was evident both clinically and radiographically in eight threaded (seven Biomet T-Tap cups and one Lord cup) and four press-fit, porous-coated uncemented (two Biomet Universal and two Biomet Mallory cups) acetabular components. In addition, 14 hips underwent or were scheduled to undergo revision of failed liners because of excessive wear (Table 27).

Three patients (three hips) had multiple cup revisions; all were performed for aseptic loosening of the acetabular component.

**Table 27.** Revisions of the acetabular components.

| **Brand** | ***N*** | **Reason for revision** | n | Component used in revision | **n** |
|---|---|---|---|---|---|
| Lord | 1 | Aseptic loosening | 1 | Biomet Vision | 1 |
| Biomet T-Tap | 8 | Aseptic loosening | 7 | Biomet Universal | 6 |
| | | | | Biomet SHP (cemented) | 1 |
| Biomet Universal | 25 | Aseptic loosening | 2 | Biomet Universal | 1 |
| | | | | Ogee (cemented) | 1 |
| | | Broken augment | 1 | Lubinus IP (cemented) | 1 |
| | | Excessive liner wear | 7* | New PE liner cemented inside the shell | 4* |
| Biomet Mallory | 34 | Aseptic loosening | 2 | Biomet Universal | 2 |
| | | Liner wear + granulomas | 1 | Elite (cem.) + Kerboul antiprotrusion | 1 |
| | | Excessive liner wear | 7* | New liner cemented inside the shell | 2* |

* Eight hips were scheduled for liner revision at the final follow-up examination (three Universal and five Mallory cups). All cemented cup revisions were performed in other hospitals. N = number of primary operations. n = number of revisions. PE = polyethylene.

The 10 year survival rate for press-fit, porous-coated acetabular components (Biomet Universal and Biomet Mallory) was 95% (95% CI 89–100) with aseptic loosening as the end point (Figure 20) and 88% (95% CI 81–95) with revision of the cup for any reason as the end point (Figure 21). The overall survival rate of press-fit, porous-coated cups was significantly better than that of smooth-threaded cups ($p<0.001$). Eight of the nine threaded acetabular components were revised, and the remaining one was found to be loose under radiographical examination at the time of final follow-up. The patient with the loose cup was not able to attend the final follow-up examination in person owing to poor general health and to medical conditions unrelated to her hip disease. However, she was interviewed by telephone and her hip was, painless, therefore revision of the cup was not proposed.

The liner was revised in six hips (five patients; four Universal and two Mallory cups), due to excessive PE wear. In each of these re-operations a new liner (Biomet Vision) was cemented inside the well-fixed metallic shell. In addition, eight hips (seven patients; three Universal and five Mallory cups) were scheduled for liner revision at the final follow-up examination.

Recurrent dislocation occurred in one hip, which had a well-oriented acetabular component. The patient was treated with wall augmentation of the acetabular component using a semilunar piece of liner rim fixed by three screws. The outcome was successful.

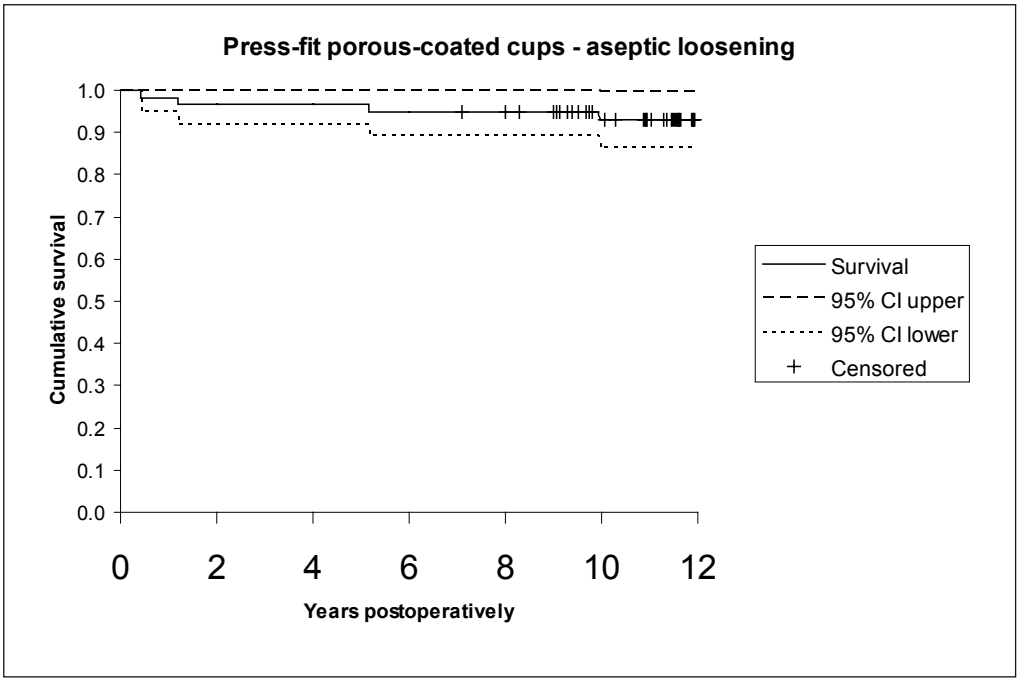



**Fig 20.** Kaplan-Meier survival curve of press-fit porous-coated acetabular components with aseptic loosening as the end point.

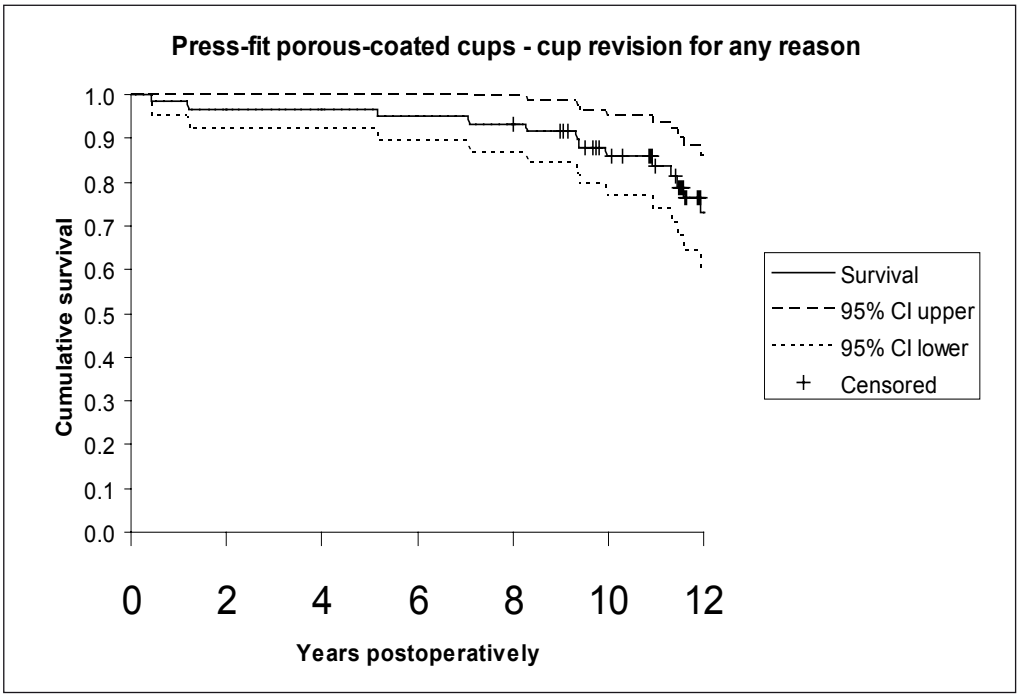



**Fig 21.** Kaplan-Meier survival curve of press-fit porous-coated acetabular components with any cup revision (including exchange of liner) as the end point.

The revision rate of the femoral component was 7%. One Biomet CDH stem was revised for aseptic loosening 3.3 years after the primary operation. Another Biomet CDH stem was undersized, and was revised with a larger Biomet CDH stem five months after the primary operation. One Lord Madréporique stem and two Biomet CDH stems were revised because of malpositioning (see Complications section 9.2.4.) with Biomet CDH stems at a mean of 16 days (range, 8–28 days) after the primary operation. The survival rate of the Biomet CDH stem was 98% (95% CI 97–100) at 10 years using aseptic loosening as the end point. When the end point was defined as stem revision for any reason, the 10-year survival rate for the Biomet CDH stem was 94% (95% CI 88–100) (Figure 22).

Radiographical examination revealed evidence of fibrous union of the transposed trochanter in three of the 68 hips studied. One patient with bilateral fibrous unions of the greater trochanter had no limp, his hips were also painless, the Trendelenburg sign was negative, and the abduction strength of both hips was strong at the time of final follow-up.

### 9.2.2.2 Prosthetic components in patients with a previous Schanz osteotomy of the femur (V)

The revision rate of the acetabular component was 59%. Aseptic loosening was evident both under clinical and radiographical examination for 18 threaded (Biomet T-Tap) and one press-fit, porous-coated

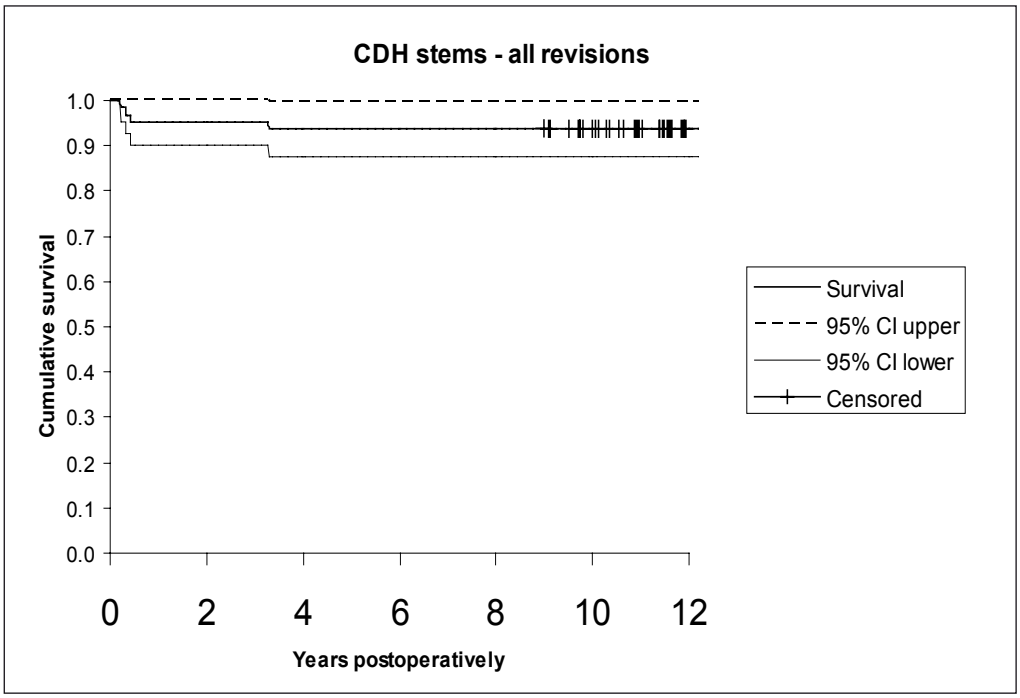



**Fig 22.** Kaplan-Meier survival curve of the CDH stem with stem revision for any reason as the end point.

uncemented (Biomet Universal) acetabular components. In addition, 16 hips underwent or were scheduled to undergo revision of failed liners due to excessive PE wear (Table 28).

Of the four deceased patients (four hips), one had been scheduled and two had already undergone cup revision for aseptic loosening of the threaded acetabular component.

In total, 10 patients (ten hips) had multiple cup revisions: three hips for aseptic loosening of the acetabular component, two hips for liner wear and recurrent dislocation, and three hips for aseptic loosening and liner wear. Moreover, one hip had two revisions for liner wear, and for one hip a first revision was performed for technical error and a second revision for liner wear.

The 10 year survival rate for press-fit, porous-coated acetabular components (Biomet Universal, Biomet Mallory and Biomet Vision) was 98% (95% CI 94–100) with aseptic loosening as the end point (Figure 23), and 69% (95% CI 56–82) with revision of the cup for any reason as the end point (Figure 24). The overall survival rate of press-fit, porous-coated cups was significantly higher than that of the smooth-threaded cups ($p<0.001$). As many as 16 of the 18 threaded acetabular components were revised, and the remaining two were found to be loose under radiographical examination at the time of final follow-up. Consequently, these were scheduled for cup revision.

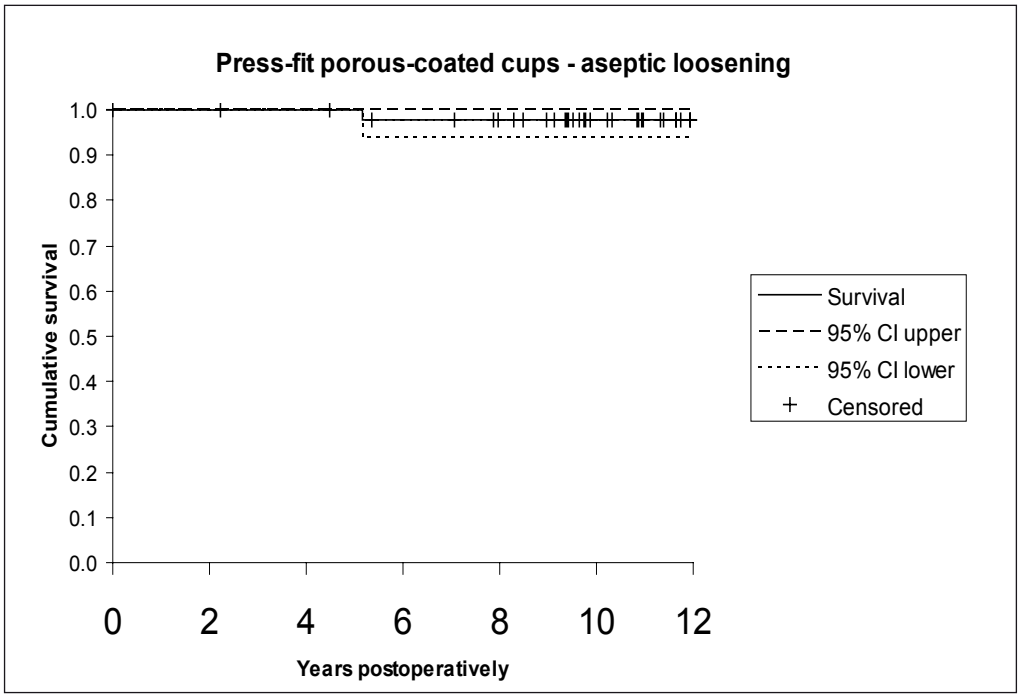



**Fig. 23.** Kaplan-Meier survival curve for the press-fit, porous-coated acetabular components, with revision because of aseptic loosening as the end point. CI = confidence interval.

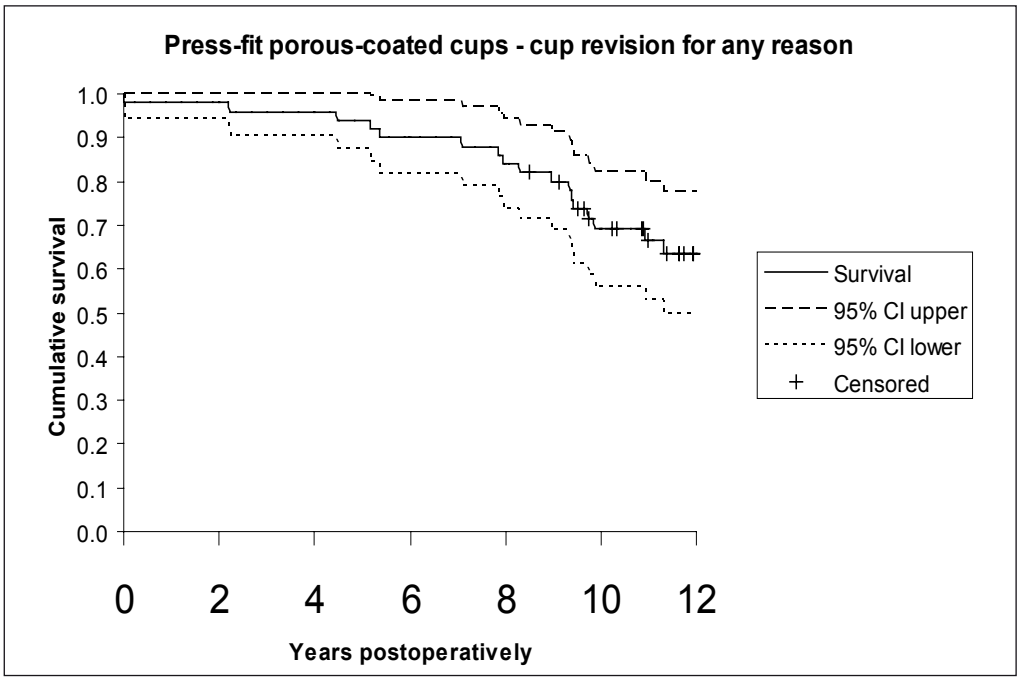



**Fig. 24.** Kaplan-Meier survival curve for the press-fit, porous-coated acetabular components, with cup revision for any reason as the end point. CI = confidence interval.

For 14 hips (12 patients; 10 Universal and four Mallory cups), the liner was revised due to excessive PE wear. In each of these revisions a new liner (Biomet Vision) was cemented inside the well-fixed metallic shell. Two hips (two patients; two Mallory cups) were scheduled for liner revision at the final follow-up examination. In addition, in three hips with well-fixed acetabular components (three patients, one Universal and two Mallory cups) severe liner wear had lead to the widespread proliferation of granulomas. Consequently, cups had to be removed, granulomas were excised and replaced with allogeneous bone grafts, and acetabular reconstruction was performed with antiprotrusion devices and cemented cups (Table 28).

**Table 28.** Revisions of the acetabular components.

| Brand | *N* | Reason for revision | n | Component used in revision | n |
|---|---|---|---|---|---|
| | | | | Biomet Universal | 12 |
| | | | | Lubinus IP (cemented)[1] | 2 |
| Biomet T-Tap | 18 | Aseptic loosening | 18 | Biomet SHP (cemented)[1] | 1 |
| | | | | Exeter (cemented) | 1 |
| | | | | Scheduled for revision | 2 |
| | | Aseptic loosening | 1 | Biomet Universal | 1 |
| | | Technical error[2] | 1 | Biomet Universal | 1 |
| Biomet Universal | 32 | Recurrent dislocation | 1 | Acetabular augmentation | 1 |
| | | Liner wear + granulomas[1] | 1 | Ogee (cem.) + Howmedica support mesh[1] | 1 |
| | | Excessive liner wear | 10 | New PE liner cemented inside the shell | 10 |
| | | Liner wear + granulomas | 1 | Exeter (cem.) + Ganz antiprotrusion | 1 |
| Biomet Mallory | 18 | Liner wear + granulomas[1] | 1 | Elite (cem.) + Kerboul antiprotrusion[1] | 1 |
| | | Excessive liner wear | 6[3] | New PE liner cemented inside the shell[3] | 4[3] |

[1] Cup revision performed in another hospital.
[2] The cup was placed too medially. In the postoperative radiographs, the cup had turned horizontally and protruded medially. It was revised with a larger Universal cup, that was placed on a more lateral and cranial position.
[3] Two hips were scheduled for liner revision at the final follow-up examination (two Mallory cups).
N = number of primary operations. n = number of revisions. PE = polyethylene.

Recurrent dislocation occurred in one hip with a well-oriented acetabular component. The patient was treated by augmentation of the wall of the acetabular component with a semilunar piece of liner rim fixed by three screws. The outcome was successful.

The rate of revision of the femoral component was 11%. Four Biomet CDH stems were revised for aseptic loosening, at a mean of 3.8 years (range, 3.3–4.9 years) after the primary operation. Two of these four stems were clearly undersized, and in another two cases the greater trochanter had been detached so far distally, that lateral support and rotational stability of the stem was deficient. All four stems were revised with larger Biomet CDH stems. Two Biomet CDH stems were revised because of malpositioning (see Complications section 9.2.4); they were replaced with a Biomet CDH stem at eight and 12 days after the primary operation. The survival rate of the Biomet CDH stem was 92% (95% CI 86–99) at 14 years using aseptic loosening as the end point. When the end point was defined as stem revision for any reason, the 14-year survival rate for the Biomet CDH stem was 88% (95% CI 81–96) (Figure 25).

The two patients who declined to participate in the study, had both undergone stem revision. One patient underwent revision because of aseptic loosening of a clearly undersized Biomet CDH stem 3.8 years after the primary operation; the loose CDH stem was replaced with a Head-Neck (Biomet) stem. The second patient underwent revision only three months after the primary operation, as the Biomet CDH stem had subsided, turned into retroversion and fractured the medial femoral cortex; the loose stem was replaced with a larger CDH stem. None of the four deceased patients (four hips) had undergone stem revision.

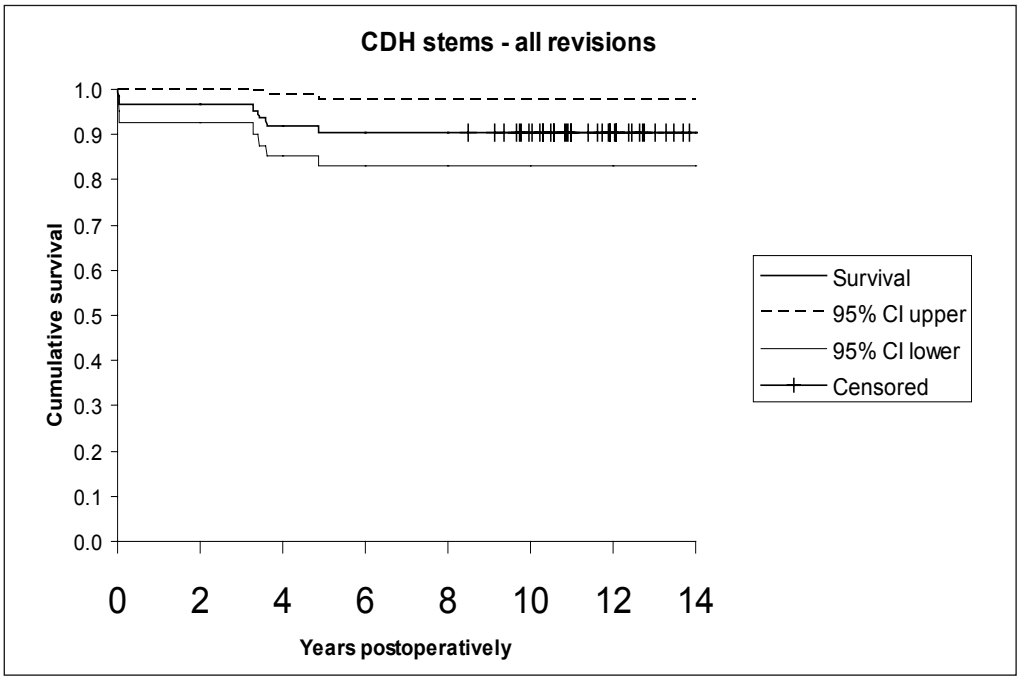



Fig. 25. Kaplan-Meier survival curve for the CDH stems, with stem revision for any reason as the end point. CI = confidence interval.

Radiographical evidence of fibrous union of the transposed trochanter was noted in two of the 68 hips. The patient with bilateral fibrous unions of the greater trochanter had no limp, his hips were painless, the Trendelenburg sign was negative, and the abduction strength of both hips was strong at the time of final follow-up.

## 9.2.3 Radiographical results

### 9.2.3.1 Radiographical results in patients with high congenital dislocation (IV)

Heterotopic ossification was observed in three of the 68 hips; the ossification was Brooker class I in two hips, and class II in one hip.

#### 9.2.3.1.1 Femoral component

Alignment of the femoral component was classified as neutral in 62 hips (97%), valgus in one, and varus in one. All cementless femoral components provided evidence of bone ingrowth under radiographical examination at the last follow-up. One hip had femoral osteolysis measuring 110 $mm^2$ in zone 1, but there was no distal osteolysis.

#### 9.2.3.1.2 Acetabular component

The mean acetabular cup angle was 49° (range, 34° –74°). At the time of final follow-up, one hip exhibited both migration of the acetabular component and a 4-mm thick radiolucent line in zone 1. Two hips with unrevised cups had periacetabular osteolysis, the osteolytic lesion measuring 431 $mm^2$ in all three zones in one hip and 450 $mm^2$ in zone 3 in the other hip. None of the 14 patients who underwent cup revisions had radiolucent lines or migration of the revised acetabular component at the time of final follow-up. All bone grafts used to reinforce the acetabular roof united and the centralized medial walls of the acetabulum healed without complications.

At the time of the final follow-up evaluation, 15 of the 67 hips (22%) had linear wear of the PE liner measuring from one to five millimeters in depth. Two of these hips had periacetabular osteolysis. Seven patients (eight hips) were scheduled for liner revision at the final follow-up examination.

### 9.2.3.2 Radiographical results in patients with a previous Schanz osteotomy of the femur (V)

Heterotopic ossification was observed in four of the 68 hips; the ossification was Brooker class I in two hips, class II in one hip and class III in the other hip.

#### 9.2.3.2.1 Femoral component

Alignment of the femoral component was classified as neutral in 67 hips (99%), and valgus in one. All cementless femoral components provided radiographical evidence of bone ingrowth at the last follow-up evaluation. Three hips had femoral osteolysis in zone 1, measuring 32 $mm^2$ in one hip, 110 $mm^2$ in the second hip, and 338 $mm^2$ in the third hip. There was no distal osteolysis in any of these hips.

#### 9.2.3.2.2 Acetabular component

The mean acetabular cup angle was 50° (range, 30°–71°). All bone grafts used to reinforce the acetabular roof united and the centralized medial walls of the acetabulum healed without complications. At the time of final follow-up, one hip exhibited both migration of the socket and 2-mm thick radiolucent lines in zones 1 and 2 and a 12 mm thick line in zone 3. The patient was scheduled for revision of the threaded acetabular component. Another hip exhibited both migration of the socket and a 4 mm thick radiolucent line in zone 3; she was already scheduled for cup revision in another hospital. One hip with an unrevised cup had a periacetabular osteolytic lesion, which measured 450 $mm^2$ and was in zone 3; this hip manifested a 3 mm deep linear wear of the PE liner; the patient was scheduled for liner revision and bone grafting of the osteolytic lesion. One hip with a previous cup revision (Biomet T-Tap cup revised to a cemented Exeter cup) exhibited both migration of the socket and a 2 mm thick radiolucent line in zone 3. The patient

was scheduled for a second revision of the acetabular component. One hip with a revised cup (Biomet T-Tap cup revised to a Universal cup) had periacetabular osteolysis, the osteolytic lesion measuring 800 $mm^2$ in zone 1. In addition, this patient had linear wear of the PE liner measuring 3 mm in depth, and was scheduled for liner revision and bone grafting of the osteolytic lesions. None of the other 36 patients who underwent cup revisions had radiolucent lines or migration of the revised acetabular component at the time of final follow-up.

At the time of the final follow-up evaluation, nine of the 68 hips (13%) had linear wear of the PE liner with the depth of the wear ranging from 0.5–3 mm. Two of these hips had periacetabular osteolysis. Two patients (two hips) with original acetabular components and one patient (one hip) with a revised cup were scheduled for liner revision at the final follow-up examination.

## 9.2.4 Complications (IV and V)

### 9.2.4.1 Complications in patients with high congenital dislocation, without a previous Schanz osteotomy

When patients with high congenital hip dislocation, but without a previous Schanz osteotomy (28 patients, 34 hips), were analyzed separately, there were 10 perioperative complications (29%): three instances of peroneal nerve palsy, one femoral nerve palsy, one superior gluteal nerve palsy, four non-displaced fractures of the proximal part of the femur, and one early dislocation secondary to malpositioning of the stem. None of the femoral fractures occurred secondary to the femoral splitting osteotomies. There was one proximal femur fracture identified during canal rasping and three fractures identified during stem insertion. Two of the fractures were fixed using Parham bands, one was fixed by the same lag screws used to secure the transposed greater trochanter, and one was fixed with Dall-Miles cables (Howmedica International, Rutherford, NJ, U.S.A.) combined with autologous cancellous bone grafting. All healed without affecting the final outcome of the operation.

One patient who presented with peroneal nerve palsy on the first postoperative day, had a clinically apparent haematoma in the buttock; in addition, the leg had been lengthened by five centimeters. The haematoma was evacuated urgently, and the femur was shortened by one centimeter; the palsy fully resolved in six months. A second patient also presented with peroneal nerve palsy on the first postoperative day. However, this patient's buttock was soft, and the leg had been lengthened by only three centimeters. She was kept under observation and the palsy fully resolved itself in six months. A third patient presented with peroneal nerve palsy two months postoperatively. Even though electroneuromyography revealed a lesion in the fifth lumbar nerve root, clinical examination revealed tenderness in the peroneal nerve at the level of the knee. We explored the peroneal nerve, which was found to be entrapped under the sharp fibrous edge of the peroneus longus origin. Consequently, the nerve was released around the fibular neck. Despite decompression, this palsy did not fully resolve, and the patient had a permanent incomplete drop foot at the time of the last follow-up examination.

The femoral nerve palsy did not fully resolve, although quadriceps function gradu-

ally returned, and there was 80% force (as demonstrated by subjective manual testing) compared with that on the unaffected side 11.9 years after the primary operation. The patient with the superior gluteal nerve palsy had a spontaneous recovery within six months.

The only early dislocation was secondary to malpositioning of the stem. The patient with a malpositioned Lord Madréporique stem underwent a re-operation to replace it with a CDH stem on the 28th postoperative day.

A fracture of the greater trochanter was diagnosed in one patient who had fallen 1.2 years after the operation. The trochanter was re-attached by screws and augmented with a hook plate; it healed well.

One early stem revision (five months postoperatively) was due to the insertion of too small a stem originally, which resulted in incomplete osseointegration and the early loosening of the stem.

### 9.2.4.2 Complications in patients with a previous Schanz osteotomy of the femur (V)

Fifteen perioperative complications (22%) occurred in patients with a previous Schanz osteotomy: two instances of peroneal nerve palsy, two femoral nerve palsies, one obturatorius nerve palsy, five non-displaced fractures of the proximal part of the femur, one malpositioned stem perforating the posteromedial cortex of the femur, one malpositioned cup perforating the acetabulum and lying horizontally, one superficial wound infection, one pulmonary embolism, and one early dislocation secondary to malpositioning of the stem.

None of the femoral fractures occurred secondary to the femoral splitting osteotomies. There was one proximal femur fracture identified during canal rasping and four fractures identified during stem insertion. Three of the fractures were fixed with Parham bands and two were fixed with Dall-Miles cables (Howmedica International, Rutherford, NJ, U.S.A.) combined with autologous cancellous bone grafting. Two of these fractures occurred in hips with metaphyseal segmental angular correction and shortening osteotomy. All healed without affecting the final outcome of the operation.

One patient who presented with peroneal nerve palsy on the second postoperative day, had a clinically apparent haematoma in the buttock. This haematoma was massive and locally compressed the sciatic nerve, thus it was evacuated urgently. The sciatic nerve was found to be macroscopically normal. Despite decompression the palsy did not resolve and the patient presented with a permanent complete drop foot at the time of the last follow-up examination. Another peroneal nerve palsy was observed on the first postoperative day and compression of the sciatic nerve by haematoma was suspected. The hip was explored, but there was no haematoma in the locality of the sciatic nerve. Instead, the sciatic nerve was found to impinge on the posterior wall of the acetabular component when the hip was in flexion. The femoral head was exchanged to a shorter one, and the impingement was relieved. However, the palsy did not resolve, and at the time of the last follow-up examination this patient also presented with a permanent complete drop foot. The two patients who presented with femoral nerve

palsy postoperatively (on the fifth and on the first postoperative day) had each a clinically apparent haematoma in the groin. The haematoma was evacuated urgently in both patients and bleeding arteries were electrocoagulated. The palsy of the first patient fully resolved within three months. The motor paresis of the second patient fully resolved within six months, but at the time of the final follow-up the patient presented with a permanent sensory deficit in the thigh. One patient had a superior gluteal nerve palsy, and another patient presented with an obturatorius nerve palsy. Both patients recovered spontaneously within six months.

In one patient, a CDH stem was inserted in excessive anteversion causing an early dislocation. Consequently, a re-operation to insert the malrotated stem in correct rotation was performed on the 12th postoperative day. During insertion one CDH stem perforated the posteromedial cortex of the femur. The malpositioning was evident in the postoperative radiographs, and the stem was revised on the eighth postoperative day. For one patient, the cup was placed too medially. In the immediate postoperative radiographs, the cup had perforated the medial wall of the acetabulum and turned horizontally. A re-operation was performed on the second postoperative day; a new cup was placed in a more lateral and cranial position and autogenous bone grafting was performed to augment the lower medial wall of the acetabulum. The revised cup was found to be radiographically well-fixed at the time of the final follow-up.

One patient was diagnosed with pulmonary embolism postoperatively. She was treated with peroral warfarin for three months, and experienced no residual symptoms.

A superficial wound infection, caused by *Staphylococcus aureus*, in one patient was treated with oral antibiotics and healed well.

# 10 Discussion

## 10.1 Validity of the data

Certain limiting factors and selection bias are inherent in most clinical studies and this is also true of our studies.

### 10.1.1 Register-based studies (I, II and III)

Register-based studies provide valuable insight into the use of the THA procedure in a certain patient-group, as the number of arthroplasties studied is substantially larger in register-based studies than in clinical studies from single centers (Kim et al. 2002). In addition, such nationwide studies enable trends in THAs to be shown more clearly and on a larger scale. Further, the results can be compared with those of other Nordic arthroplasty registers giving a broad perspective on the results for both single implants and the methods applied in respect of THA. The statistical methods used in our study were valid, as we applied not only the Kaplan-Meier survival analysis but also the Cox multiple regression analysis to take account of confounding factors. The importance of considering confounding factors in the survival analysis of hip implants has been shown previously (Furnes et al. 2001).

Nevertheless, we acknowledge that the current register-based studies have certain limitations. For instance, we were not able to report any subjective outcome measurements such as that found in the HHS or disease-specific quality of life measurements. Moreover, in register-based analyses comprising thousands of patients, it is not possible to conduct radiographical examinations with the consequence that silent osteolysis *inter alia* cannot be detected. A register-based study such as ours may also have diagnostic pitfalls regarding young patients, in that a small proportion of the patients (females in particular) diagnosed with primary osteoarthritis may in fact have mild developmental dysplasia (Harris 1986). It has been reported that patients with developmental dysplasia of the hip have poorer outcomes to THA than other patient groups (Furnes et al. 2001).

There is some heterogeneity in the design concept groups in study I; first, the concept of uncemented uncoated stems included both failed designs and designs with reported good results. Second, concepts of proximally HA-coated and extended porous-coated uncemented stems each included only two designs. However, major design concept groups (i.e. cemented stems and proximally porous-coated uncemented stems; all-poly cemented cups and press-fit porous-coated uncemented cups) included a lot of brands, none of which have previously been reported as failures.

In study II, the most frequently used components were implanted between 8–15 times more often than the most infrequently used implants. It is notable, that this may cause some bias in the results; e.g. rarely used designs may only have been implanted in one centre, and if the surgical technique of the centre has been suboptimal, results of the particular implant will not reflect its true performance. On the other hand, results of a THR may be unrealistically good, if it they have been implanted in a single specialized

center by an orthopaedic surgeon of exceptional expertise at THA. As Biomet's endoprostheses were so commonly used, their benefits and pitfalls may be overemphasized in this study.

When survival rates of hip implants are evaluated, it is important to analyze and report both the independent survival rates of femoral and acetabular components and the survival rate of the whole prosthesis. Similarly, both aseptic loosening and all revisions should serve as end points separately. A good example is the Biomet Bi-Metric – Universal prosthesis; if we look at the 13-year survival rate of the Bi-Metric – Mallory THR (74%) in study II, it seems that this uncemented THR has an unacceptably poor performance. However, more accurate analysis revealed, that the Bi-Metric stem *per se* has a very good survival rate. On the other hand, the Universal cup with a HexLoc™ liner had a satisfactory survival rate of 93% at 10 years with aseptic loosening as the end point, but other revisions (including exchange of the PE liner in particular) markedly impaired its results. This is in agreement with a previous report by Puolakka and colleagues (1999) on the (non age-dependent) data taken from the same register.

### 10.1.2 Clinical studies (IV and V)

We retrospectively analyzed the results of uncemented THA in patients with high congenital hip dislocation and those of patients with severely dysplastic hips that had been previously treated with a Schanz osteotomy of the femur. The follow-up time was >10 years for 86% (50/56) of the patients in study IV and 92% (54/59) of the patients in study V, respectively. The participation rates for studies IV and V were 95% and 97%, respectively. Active abduction was selected as a measure of abduction muscle function because of its reported sensitivity (Mallory 1974) and its relative functional significance when compared with passive abduction (Charnley and Ferreiraade 1964). However, abduction strength was measured preoperatively by only the Trendelenburg's test. Survival of THA was analyzed by the Kaplan-Meier method, and valid principles of hip implant survival analysis were followed (Dorey 2004).

## 10.2 General discussion

### 10.2.1 THA in young patients – in the light of a national register

#### 10.2.1.1 Gender distribution and effect on prosthesis survival (I and III)

In study I, the majority of the younger patients who underwent THA for primary OA were males. This gender distribution differs from that of patients aged 65 years or older when undergoing THA for primary OA over the same study period: of which 65% (n=19 701) were females and 35% (n=10 622) males ($p<0.001$) (Nevalainen 2004). The reason for the different gender distribution among young OA patients is unclear. Earlier studies have shown that THAs are performed more frequently in females than in males, even among younger patients (Paavolainen et al. 1991, Havelin et al. 2000, Puolakka et al. 2001b, Malchau et al. 2002). However, the data of the Danish and Australian hip registers show that >50% of younger patients undergoing THA (all diagnoses) were males (AOA 2004, DHR 2004).

One possible explanation is that males are more active physically and thus their hips are subject to subtle microtraumas that accelerate the degenerative process. Thus, hip OA may develop earlier in males. Alternatively, males are less likely to accept physical impairment and end up undergoing THA earlier than females. Epidemiological studies provide evidence that physical activity, whether through participating in sports or having a physically strenuous occupation, increases the risk of hip OA (Vingard et al. 1991, Croft et al. 1992a, Croft et al. 1992b, Vingard et al. 1993). However, these studies have not demonstrated that gender is an independent risk factor for hip OA. In study III we found that most patients undergoing THA for RA were females, which agrees with other studies (Creighton et al. 1998, Lehtimaki et al. 1999, Keisu et al. 2001).

Females had a higher risk of cup revision than males in young patients with primary OA (I). To our knowledge, this finding has not been reported previously. The aetiology remains obscure. In young patients with RA (III), there was a trend towards poorer stem survival in males than in females. In two large clinical studies of Charnley LFA, males were found to have an increased risk of stem revision as compared to females (Hozack and Rothman 1990, Lehtimaki et al. 1999). Men may apply more powerful torque forces to the femoral component, leading to aseptic loosening of the stem. This may partially explain the difference in stem survival between the genders.

#### 10.2.1.2 The effect of age on prosthesis survival (I and III)

The poorer survival of prostheses in young patients on a nation-wide level has been reported in the literature earlier (Havelin et al. 2000, Malchau et al. 2002). The poorer survival of THAs in young OA patients in the present study seems to be related primarily to the inferior implant types more commonly used in their operations rather than the age of the patient. In the present studies, the younger age group (<46 years) had an increased risk of cup revision as compared to the older age group (46-54 years) in patients with primary OA (I) and in patients with RA (III). This is in accordance with that found in a previous study (Lehtimaki et al. 1999). Apparently, young and active patients put stresses on their hip joints more than older patients, a tendency that leads eventually to aseptic loosening of the cup.

#### 10.2.1.3 Hospital volume (I)

It is unclear whether the revision results would improve, if THAs were performed in young patients in centralized and specialized facilities, or if these patients were also concentrated in tertiary centres. In this study, the results were no better for hospitals performing more than 10 THAs on young patients with primary OA than those for other hospitals performing fewer than 10. It is possible that the hospitals in which a high number of THAs were performed also treated the youngest and most difficult patients. In retrospect, the hospitals working as tertiary referral centres in Finland made some poor choices, using new, undocumented uncemented implants that were not introduced into smaller hospitals until later (Puolakka et al. 1999, Puolakka et al. 2001b).

### 10.2.1.4 Trends in prosthetic components (I and III)

A very wide range of femoral and acetabular components were used by Finnish orthopaedic surgeons for young patients with primary OA (I) and RA (III) during the study period. Over 50% of all implant designs used in patients with primary OA and >70% of all designs used in patients with RA were used in fewer than 20 operations. A similar pattern of uses has been reported in Norway (Havelin et al. 2000). This phenomenon might be attributed to commercial influences on orthopaedic surgeons. However, the three most commonly used stems accounted for 72% of all stems implanted in patients with primary OA and 70% of all stems implanted in patients with RA at the end of the study period (2000–2001 in primary OA, 2002–2003 in RA). A similar usage profile emerged for cups in patients with OA (I). The three most commonly used cups accounted for 64% of all cups. Even so, the situation was still not optimal in patients with RA, where the three most commonly used cups accounted for less than 50% of all cups implanted. This finding may reflect the problem of acetabular component loosening encountered in patients with RA; the search for the best acetabular solution still goes on.

The proportion of uncemented stems and cups used in young patients with either primary OA, or with RA rose dramatically from the beginning of the study period to the early 1990s. This upward trend reflects improvements in uncemented implant designs. However, this trend appears to have reversed at the beginning of the 21st century. This probably partly reflects poor experiences associated with the earlier uncemented design concepts. The proportions of cemented and uncemented implants used nationwide have only been reported on data from the Nordic countries' registers. The use of uncemented implants is most common in Finland. In Norway, 18% of acetabular and 13% of femoral components were uncemented in 1988 and 1998 (Havelin et al. 2000). In Denmark, 64% of all hip prostheses implanted during 1995–1998 were cemented (Lucht 2000).In Sweden, cemented designs were used in 93% of all hip arthroplasties implanted in 2000 (Malchau et al. 2002). However, it should be noted that the findings from the registers of other Nordic countries include all age groups, not only young patients. Moreover, not all Nordic countries use the same implant designs. Therefore, the results for cemented and uncemented implant subgroups cannot be directly compared between registers. Although uncemented implants have been used more commonly in Finland, there is also wide experience of cemented THA. For example, 50% of all cups (n=25 150) and 39% of all stems (n=19 991) implanted in Finland during 1991–2001 (all age and diagnosis groups) were cemented (Nevalainen 2004).

### 10.2.1.5 Stem design concepts (I and III)

Proximally circumferentially porous-coated and HA-coated uncemented stem design concepts gave better results than cemented stems in young patients with primary OA (I). Similarly, proximally circumferentially porous-coated stems gave higher long-term survival rates than cemented stems in young patients with RA (III). The results of cemented stems implanted with a sec-

ond-generation cementing technique that have been reported in the literature (Barrack et al. 1992, Ballard et al. 1994, Emery et al. 1997, Kobayashi et al. 1997, Smith et al. 2000) have not been any better than the results of fixation using first-generation techniques (Collis 1991, Boeree and Bannister 1993, Joshi et al. 1993, Neumann et al. 1996, Devitt et al. 1997, Sochart and Porter 1997b, Sochart and Porter 1997a, Sochart and Porter 1998, Keener et al. 2003). Results of third-generation cementing techniques in younger patients have not been published so far. Despite the systematic instruction of Finnish orthopaedic trainees and consultants in modern third-generation cementing techniques during the 1990s, the results for cemented stems did not improve significantly from the 1980s to the 1990s in young patients with either primary OA or RA. What is more, modern uncemented stems implanted during the 1990s provided considerably better results than cemented stems. The improved performance of uncemented proximally porous-coated stems implanted in young patients with primary OA during the 1990s is an important finding. The results for some uncemented stems implanted at specialized centres have been good (McLaughlin and Lee 2000, Kim et al. 2002, Aldinger et al. 2003, Capello et al. 2003, Jacobsen et al. 2003, Kim et al. 2003a, Kim et al. 2004). Moreover, the results taken from the Swedish register also showed a trend towards better survival of uncemented implants in young patients (Malchau et al. 2002). However, our study is the first to confirm good results for modern uncemented stems on a nation-wide level in the two largest patient groups among young patients. Even though the follow-up of proximally HA-coated uncemented stems was relatively short in both studies (I and III), it is notable, that there is so far only one study that has reported long-term results of HA-coated stems in young patients (Capello et al. 2003).

#### 10.2.1.6 Uncemented stem designs (II)

All proximally porous-coated uncemented stems studied gave good (>90%) 10 year survival rates when either aseptic loosening or any stem revision was used as the end point. Furthermore, the Biomet Bi-Metric stem had an excellent 15-year survival rate. Good results in younger patients with the Bi-Metric stem (Jacobsen et al. 2003) and with the Profile Porous stem have been reported earlier (Kim et al. 2003b) from single centres. Now those results are also confirmed by our nation-wide study (study II). Recently, Archibeck et al. (2001) reported a 100% survival rate at 10 years for an Anatomic Mesh uncemented stem in 78 hips (74 patients with a mean age of 52 years at the time of arthroplasty. However, our data suggest that survival of an Anatomic femoral component was clearly poorer than those results previously reported by Archibeck, and was significantly worse than that for the Bi-Metric stem when either aseptic loosening or any stem revision served as the end point. The reason for this difference remains unclear. Thanner et al. (1999) reported an 84%, 10 year survival rate for the PCA Std stem in patients with mean age of 50 years. In another series, Bojescul et al. (2003) reported a 93% survival rate for the PCA Std stem at 15 years. In the present study, performance of the PCA Std stem was comparable to those previous reports.

Keisu et al. (2001) reviewed the results of 114 consecutive THAs with the Lord

Madréporique femoral component and found a 94% survival rate at 13 years. In another study on 107 hips, the 10-year survival rate for the Lord Madréporique stem was 98% using revision as the end point (Malchau et al. 1996). However, the combined clinical and radiographical 10 year survival rate declined to 81% (Malchau et al. 1996). In our study, the extended porous-coated Lord Madréporique stem had a good 15-year survival rate, of 91% with aseptic loosening as the end point. Nevertheless, the survival of the Lord Madréporique stem overall was significantly worse than that of the Bi-Metric stem with revision for aseptic loosening of the stem as the end point.

The only proximally HA-coated uncemented stem reported on in this study (ABG I stem) performed well with an excellent 10-year survival rate of 97% with any stem revision as the end point. Good mid-term results have been reported with the ABG I stem from single centres (Tonino and Rahmy 2000, Giannikas et al. 2002, Blacha 2004). However, it is unclear whether HA-coating improves osseointegration in the short-term and resistance to aseptic loosening of porous-coated stems in the long-term. In their prospective randomized trial of 100 hips, Kim et al. (2003a) recently compared porous-coated stems with and without additional HA-coating; the authors concluded, that after mid-term follow-up, the HA coating on the porous surfaces did not improve or diminish the results of THA with the femoral component design used in their study. Park et al. (2003) reported on the results of 24 patients with bilateral arthroplasties, who received a porous-coated femoral component in one and a HA-coated femoral component in the other hip. These authors found no differences between the groups in clinical and radiological results at a minimum follow-up of 4 years.

The CLS Spotorno stem, which has a completely different design concept from the other modern uncemented stem types (the only grit-blasted macro-porous titanium stem in the study), gave an excellent 10 year survival rate. This is in accordance with previous reports from single centres (Schramm et al. 2000, Aldinger et al. 2003, Kim et al. 2004). The double-wedge design of the CLS Spotorno stem seems to provide good primary stability as well as osseointegration. Although the number of CLS stems in study II was rather small (108), these operations were performed in several hospitals and by several orthopaedic surgeons. Thus, good results of the CLS Spotorno stem seem to be reproducible on a nation-wide level. The CLS Spotorno stem may offer a good option to modern porous- or HA-coated uncemented stems.

#### 10.2.1.7 Cup design concepts (I and III)

In this study (I), the design concepts of press-fit porous-coated and HA-coated uncemented cups performed well among young patients with primary OA. The poor survival of the uncemented cups implanted in the 1980s is tentatively attributed to the widespread use of uncemented smooth-threaded cups (Engh et al. 1990, Tallroth et al. 1993, Simank et al. 1997) and uncemented cups with inferior locking mechanisms of the PE liner (Chen et al. 1995, Scott et al. 2000, Puolakka et al. 2001a, Young et al. 2002). In the present study (I), survival of press-fit porous-coated uncemented cups was better than that of all-poly cemented cups with revision for aseptic loosening of

the cup as the end point. However, when all cup revisions (including exchange of liner), were taken into account, there was no more difference in survival between these two design concepts.

Cemented acetabular components are considered as the gold standard in THA even in younger patients. The 10 year survival rate of the cup in Charnley LFA has exceeded 90% in most of the studies (Joshi et al. 1993, Devitt et al. 1997, Kobayashi et al. 1997, Sochart and Porter 1997a, Sochart and Porter 1998), and >80% survival rates have been recorded even at 20 years (Joshi et al. 1993, Devitt et al. 1997).

The first generation of press-fit porous-coated uncemented cups has generally had poor long-term results in younger patients, with the 10 year survival rates being generally <90% (Berger et al. 1997, Duffy et al. 2001). Long-term results of second-generation porous-coated cups have been reported only with the Duraloc (DePuy, Warsaw, In., U.S.A.) acetabular component (Kim et al. 2003a, Kim et al. 2003b). In two clinical studies from the same specialized centre, the 10 year survival rate of this cup was reported to exceed >95% in the hands of one individual surgeon (Kim et al. 2003a, Kim et al. 2003b).

The follow-up of press-fit HA-coated uncemented cups was relatively short in the present study (I). Good mid-term results have also been reported for these cups in younger patients (Giannikas et al. 2002). However, long-term results of press-fit HA-coated uncemented cups in young patients have not been reported so far. Oosterbos and colleagues (2004) recently reported excellent long-term survival with the press-fit HA-coated ABG cup in older patients (≥55 years of age), but a high incidence of PE wear was a cause of concern even in this patient group. Giannikas et al. (2002) reported good medium-term results with the ABG hip in younger patients, but expressed concern when excessive PE wear of the acetabular insert was noted again. Alarmingly, wear and periacetabular osteolysis of the ABG I cup has recently been reported from another source (Duffy et al. 2004). In a recent study of 56 patients with a mean age of 44 years, Blacha (2004) reported poor results with the ABG I cup, the 9-year survival rate for the cup being 69% and for the PE liner 59%.

### 10.2.1.8 Uncemented cup designs (II)

Of the press-fit porous-coated uncemented cups, only the Biomet Universal and the Harris-Galante II showed good endurance characteristics against aseptic loosening, with over 90% survival rates at 10 years. However, 10 year survival rates of all the press-fit porous-coated cup designs declined markedly, when all cup revisions were taken into account. The Harris-Galante II cup was the only cup design with a 10 year survival rate of more than 80%. This decline resulted from multiple revisions performed mainly for excessive wear of the PE liner. For example, the 10 year survival rate of the Biomet Mallory cup declined from 88% to 61% for the same reason.

The cup / liner incongruity of the two-piece acetabular designs seems to be a common reason given for failure for most brands (Barrack et al. 1997, Malchau et al. 1997, Puolakka et al. 2001a, Young et al. 2002, Blacha 2004, von Schewelov et al. 2004). This problem was emphasized in this study (II) due to the large number of Biomet cups

used. The critical problems encountered with the HexLoc liner found in the Finnish Arthroplasty Register have been previously reported (Puolakka et al. 1999). The Biomet Vision cup, which has a closed metallic shell of titanium alloy with plasma-sprayed porous-coating (plugged screw holes) and a RingLoc liner, was introduced in Finland in 1994. In the present study (II), we found excellent short-term results for the Biomet Vision cup in young OA patients. Nevertheless, a longer follow-up is required to establish whether the Vision cup with a modern uncemented cup design concept and a RingLoc liner has less wear and osteolysis than the first-generation of modular uncemented cups. The Morscher Press-Fit uncemented cup with titanium fiber-mesh and monoblock design gave promising short-term results. Again, longer follow-up studies are required to see, what the true long-term performance of this implant is.

The PCA Pegged acetabular component gave poor results in our study (II); 76% survival rate at 10 years and 64% survival rate at 15 years is unacceptably low. The poor resistance of this cup to aseptic loosening has been reported previously (Heekin et al. 1993, Malchau et al. 1997, Thanner et al. 1999).

In the present study (II), the 10 year survival rate of the ABG I cup was 95% with aseptic loosening as the end point, but only 79% with any cup revision (including exchange of liner) as the end point. This is in accordance with the findings reported earlier (Blacha 2004). The ABG II cup had a 99% survival rate at 5 years. However, survival of the ABG II cup was not any better than that of the ABG I cup over the first five years postoperatively. As implant survival may decline markedly after 7 or 8 years (Puolakka et al. 1999, Thanner et al. 1999), longer follow-up is needed to see how the HA-coated ABG II cup will perform in the long-term.

### 10.2.1.9 Young patients with RA – special aspects (III)

Cemented THA has traditionally been considered the gold standard for the treatment of end-stage joint disease due to RA (Colville and Raunio 1978, Poss et al. 1984). However, a high rate of aseptic loosening of acetabular components has been associated with that concept, and there have also been reports of femoral component loosening. For example, Poss et al. (1984) recorded a 78% incidence of increasing radiolucency around cemented acetabular components in patients with RA at 6 –11 years after surgery, even though none had been revised. A greater incidence of both acetabular and femoral loosening has been reported in patients with RA compared with those with OA (Ranawat et al. 1980, Poss et al. 1984, Lachiewicz et al. 1986). This finding may be attributed to periarticular osteopenia, which has been associated with inactivity, medication (steroid and antimetabolites), regional hyperaemia, and increased bone turnover (Bogoch and Moran 1999).

Good results have been reported for both uncemented (Keisu et al. 2001, Lyback et al. 2004) and cemented (Lehtimaki et al. 1997, Creighton et al. 1998, Lehtimaki et al. 1999) femoral components in young patients with RA. Lybäck and colleagues (2004) reported a 100%, 10 year survival rate (with aseptic loosening as the end point) for the proximally circumferentially porous-coated Bi-Metric stem in 55 patients (mean age 28 years) with juvenile chronic arthritis in

Finland. Keisu et al. (2001) reported a 100% survival rate for another proximally circumferentially porous-coated uncemented stem design (Biomet Taperloc) at a mean follow-up of 8 years in patients with RA. In a study on 1553 consecutive Charnley low-friction arthroplasties (LFA) in 1086 patients with RA in Finland, Lehtimäki and co-workers (1999) reported a 90% survival rate for the femoral component at 15 years. In another study of Charnley LFA in patients with juvenile chronic arthritis, Lehtimäki and colleagues (1997) reported a 92% survival rate for the femoral component at 15 years. In the present nation-wide study (III) the results for proximally circumferentially porous-coated stems were better than those for cemented stems however. It appears that modern, proximally porous-coated stems achieve good primary stability and that osseointegration takes place even in patients with poorer bone-stock, such as those with RA. Thus this design concept provides young RA patients with good long-term results.

Loosening of the acetabular component remains the most serious long-term problem after THA in patients with RA. Åkesson and co-workers (1994) demonstrated that compared with the femur, the greater bone turnover in the acetabulum may contribute to the higher rate of acetabular component migration and loosening after THA in RA patients. As a possible solution to the problem of mechanical loosening, porous-coated cups were introduced in the mid-1980s. Morscher (1992) suggested that his uncemented hemispheric cups with molded PE inlays were superior to cemented cups or to other types of uncemented cup, especially in osteopenic patients with RA. On the other hand, Kirk and co-workers (1993) found no difference in the clinical outcome between cemented and uncemented cups in RA patients.

In the present study (III), survival of press-fit porous-coated uncemented cups was found to be no better than that of cemented cups with aseptic loosening as the end point. Further, when all revisions (including exchange of PE liners) were taken into account, survival of press-fit porous-coated uncemented cups was significantly poorer than that of all-poly cemented cups. However, press-fit porous-coated uncemented cups were the only design concept to demonstrate a positive cohort effect, the survival rate for cups implanted during 1992–2003 being higher than that for cups implanted in 1980–1991. The results for smooth-threaded uncemented cups were catastrophic in patients with RA. Comparative results for press-fit HA-coated uncemented cups were not as good as those for cemented cups, even in the short term, when all revisions were considered. No data on HA-coated uncemented implants in young patients with RA from either single centres or national registers have been reported to date.

In our study, uncemented THR design concepts did not perform any better than the cemented concept. On the contrary, there was a trend towards better results with the cemented THR design concept when all revisions were taken into account. With the press-fit porous-coated THR design concept, this trend appeared after 7 years of follow-up, which can be attributed mainly to the increased number of liner revisions. What gives cause for concern, is that the press-fit HA-coated concept showed a trend towards poorer survival during the first 7 years of follow-up. Numerous cup (liner)

revisions of the HA-coated cups drastically worsened the results of the press-fit HA-coated design concept. In the light of the results found here for different stem and cup design concepts, one can ask whether a reverse hybrid THR (a proximally circumferentially porous-coated stem and an all-poly cemented cup) might be the solution for young patients with RA. Unfortunately, the number of hybrid THRs in our series was too small to test this hypothesis. However, a prospective randomized controlled study might give an answer to this question.

The risk of deep infection in THA is reported to be higher in patients with RA than in those with primary OA (Wymenga et al. 1992). However, it should be noted that in the present study the number of revision operations due to deep infection in patients with RA (III) was no higher than that in patients with primary OA (I).

### 10.2.1.10 Summary of register-based studies (I, II and III)

As survival rates in patients older than 70 years of age are so good (97%–98% at 15 years) the focus of concern should be on younger and more demanding patients. The key issue for successful THA is the selection of the right implant. The results of this study suggest that the modern second-generation uncemented stems, with proximal circumferential porous- or HA-coating, seem to be a good choice for young OA patients. Furthermore, findings of the present study suggest that the modern, second-generation uncemented stems with proximal circumferential porous coating are also a good choice for young patients with RA.

Based on the results of the present study, it seems that press-fit porous- and HA-coated uncemented cups have longer endurance against aseptic loosening than cemented cups in young osteoarthritic patients, but excessive PE wear of uncemented cups is common and leads to osteolysis and liner revisions. Thus, when all revisions are taken into account, the survival of modern uncemented cups is actually no better than that of all-poly cemented cups. In young patients with RA, cemented all-poly cups should still be regarded as the gold standard. In the present study their overall performance was found to exceed that of modern uncemented cups.

In conclusion, the present study showed that young patients benefit from a modern uncemented stem implant. However, the acetabular site remains a problem from aseptic loosening of the cemented cups, and also from wear and osteolysis with the uncemented modular cups (Harris 2003). There are three possible solutions to this problem. First, the "reverse hybrid concept" (uncemented stem and cemented cup) discussed earlier (section 10.2.1.9). Second, uncemented modular cups with improved liner congruence and diminished wear properties (and/or uncemented cups with molded PE to avoid the back-side wear or loosening/breakage of the liner). Third, hard-on-hard articulations that have been widely used by orthopaedic surgeons in Finland recently. The long-term results of these three approaches in young patients are lacking. Certainly, only time will tell us the eagerly awaited answer.

## 10.2.2 Total hip arthroplasty in severely dysplastic hips (IV and V)

### 10.2.2.1 A previous Schanz osteotomy

The goal of the Schanz osteotomy was to reduce the limp in patients with severe DDH (Schanz 1922). In the present study (V), all patients had a limp and 76% of them had a positive Trendelenburg sign preoperatively, despite the previously performed Schanz osteotomy. The origin of the pain after a Schanz osteotomy seems to result from neoarthrosis in the articulation between the Schanz angle and the pelvic wall in hips with high dislocation, and secondary osteoarthritis in hips with dysplasia or low dislocation. The untreated hips with high dislocation seem to become painful later. This is supported by the findings in the present study by the mean age of the patients with a previous Schanz osteotomy undergoing arthroplasty, which was six years lower than mean age of those patients with untreated high hip dislocation (IV and V).

### 10.2.2.2 Femoral osteotomy

Based on the results of the present study (IV and V), it seems that a shortening osteotomy of the femur and transposition of the greater trochanter are a safe surgical method for treating patients with severely dysplastic hips. The technique increases both the abductor lever arm and the functional length of the gluteus medius muscle, thus creating good abduction strength. The method also ensures good and safe exposure for reconstruction of the acetabulum and femur. In the present study segmental shortening osteotomy with angular correction, combined with the step method for rotational stability, was a laborious and time-consuming procedure. Moreover, the risk of fracturing the proximal fragment is considerable, and the magnitude of functional lengthening of the leg is limited to only three centimetres (Paavilainen et al. 1993). Thus, this method was used only in hips treated previously with a unilateral low-seated Schanz osteotomy, in which it was necessary to perform a metaphyseal osteotomy to permit stem insertion and reduction of the hip within the range of safe leg lengthening. Recently, with the use of a modular femoral component with a fluted distal stem the procedure has become much easier and faster to perform, as rotational stability is achieved without the step method. Thus, this technique could be used more frequently nowadays. Although the segmental shortening technique gives a more anatomical result in radiographs, a femoral shortening osteotomy combined with distal advancement of the greater trochanter seems to give better abductor strength and a wider range of movements. The results of this study (V) support this finding, although the differences in limp and in range of movements (except extension) between these two methods lacked statistical significance.

### 10.2.2.3 Abduction strength

In the present series (IV and V), THA in conjunction with a femoral shortening osteotomy and distal advancement of the greater trochanter combined with anatomical placement of the cup, led to an increase in the abduction strength. Confirmation of this was obtained as most of the patients walked without a limp, had good active ab-

duction strength, and displayed a negative Trendelenburg sign. However, the largest available study on THA on DDH patients (Hartofilakidis and Karachalios 2004) did not report the proportion of patients limping or the presence or absence of the Trendelenburg sign postoperatively. Bruce et al. (2000) published a small study of congenitally dislocated hips on which subtrochanteric segmental shortening osteotomy with a prosthesis in situ had been performed. All osteotomies united, but six of the eight patients had a positive Trendelenburg sign postoperatively. In a study of 21 total hip arthroplasties in severely dysplastic hips, Masonis et al. (2003) reported that only 17% of the patients could walk without a limp and 61% walked with a single cane after the operation. Other studies on femoral osteotomy in THA of severely dysplastic hips have included only a small number of patients with short-term to mid-term follow-up (Yasgur et al. 1997, Chareancholvanich et al. 1999a, Perka et al. 2000), and rarely have reported anything on abduction strength of the operated hips. In the present series the Trendelenburg sign was negative in 90% of cases, and abduction strength was graded as normal or only slightly reduced in 88% of cases after the operation.

#### 10.2.2.4 Transposition of the greater trochanter

In the present study (IV and V), screw fixation of the transposed greater trochanter was found to be reliable. There were only two fibrous unions (in one patient) with slight migration of the greater trochanter. Hartofilakidis and Karachalios (2004) published a large study on 229 primary THAs in 168 patients with congenital hip disease. In that study, osteotomy of the greater trochanter was performed in all hips except for three with dysplasia, but femoral shortening osteotomy was not used on any hip. Fibrous union occurred in 13% of the hips with a low dislocation and in 22% of the hips with a high dislocation. Furthermore, non-union with migration of the greater trochanter was observed in only three hips (2%). Our union rate compares favourably with other reports on severely dysplastic hips (Bruce et al. 2000, Perka et al. 2000, Masonis et al. 2003, Hartofilakidis and Karachalios 2004).

#### 10.2.2.5 Placement of the acetabular component

Although some authors advocate placement of the acetabular component high on the pelvic floor (Russotti and Harris 1991, Jasty et al. 1995, Pagnano et al. 1996, Dearborn and Harris 1999), most advocate placing it at the level of the true acetabulum (Linde et al. 1988, Yoder et al. 1988, Karachalios et al. 1993, Paavilainen 1997, Sener et al. 2002, Hartofilakidis and Karachalios 2004, Perka et al. 2004). In their study of 90 hips with Crowe type III congenital dislocation, Stans et al. (1998) reported loosening in 83% of the cups positioned outside of the true acetabular region. A high acetabulum clinically perpetuates abductor insufficiency, limping and limb-length discrepancy. In the present study (IV and V), the cup was always seated at the anatomical level or even lower, if the anteroposterior diameter of the pelvic bone was too small.

It has been reported that, in hips in which there is a supero-lateral segmental defect but adequate anterior and posterior bone stock (such as that which occurs in dysplastic hips), 80% coverage of the

acetabular component by host bone is acceptable (Wolfgang 1990). Some authors have suggested that the protrusion socket technique originally described by Hess and Umber (1978) would be preferable, rather than using the femoral head as an autograft to augment the superolateral aspect of the acetabular rim (Hartofilakidis et al. 1998). This is mainly because a high failure rate of up to 46% at 20 years has been reported with the latter technique (Mulroy and Harris 1990, Harris 1993). In this study (IV and V), reliable fixation of the cup was always achieved without bone grafting. Augmentation of the superolateral rim with a structural graft was performed solely to increase the bone stock for future revisions. If less than 80% host bone coverage of the cup was achieved, and the cup could not be reliably fixed, the protrusion socket technique was used. An advantage of this technique is that a medialized hip centre shortens the body lever arm, and theoretically achieves better abduction function. All lateral bulk autografts united, and the centralized medial walls healed without complications. If an adequate antero-posterior diameter for an appropriately sized cup (diameter ≥44 mm) cannot be achieved at the anatomical level, inferior placement of the cup is recommended.

#### 10.2.2.6 Prosthetic components

In the present study (IV and V), revision of the uncemented porous-coated CDH stem for aseptic loosening was uncommon, and there were no radiographical signs of loosening around these stems in the long-term follow-up. In practice, all stem revisions were due to technical errors. In this study, the 10 year survival rates for revision for any reason were 94% (IV) 88% (V), and for revision for aseptic loosening the corresponding figures were 98% (IV) and 92% (V) using the Biomet CDH uncemented femoral component. This compares favourably with the two earlier reports on severely dysplastic hips with long-term follow-up (Hartofilakidis and Karachalios 2004, Lai et al. 2005).

The rate of revisions related to the problems with the acetabular components was unacceptably high in this study (IV and V), reflecting the evolution of the cementless method. All threaded uncemented cups loosened, which confirms many reports of the poor long-term survival of such cups (Engh et al. 1990, Tallroth et al. 1993, Simank et al. 1997). Press-fit, porous-coated acetabular components demonstrated a low prevalence of aseptic loosening in our series (IV and V). However, excessive wear of the PE liner of these cups resulted in numerous revisions. Because the acetabular components used in the present study were necessarily small and because a 28-mm instead of 22-mm head was implanted in the majority of cases to avoid instability of the hip, the liners were quite thin. What is more, the locking mechanism of the Biomet HexLoc liner, that was used in all press-fit, porous-coated cups in this study (IV and V), was poor and caused excessive back-side wear (Puolakka et al. 1999, Puolakka et al. 2001a).

#### 10.2.2.7 Complications

Complications were fairly common in the present series (IV and V). Preparation of the hard cortical femur was difficult and resulted in a few fractures during rasping or insertion of the prosthesis. Introduction of the collarless Biomet CDH stem later on reduced this problem, because only power

reamers were subsequently needed to prepare the femur. The majority of neurological complications in this series resolved. However, to avoid neurological injury, intraoperative electroneuromyography control is recommended when attempting to increase leg length in excess of 3 cm. Postoperatively, the extremity should be positioned in full extension of the hip joint and flexion of the knee joint to reduce tension of the sciatic nerve (Morscher 1995). Two to three weeks of postoperative bed rest has been recommended for soft-tissue readjustment in order to reduce the risk of dislocations (Hartofilakidis and Karachalios 2004). However, the protocol of early mobilization in the present study (IV and V) does not appear to have increased the rate of dislocation. There were no deep infections in this series (IV and V). Nevertheless, the complication rate is comparable to that reported in other studies of THA for severely dysplastic joints (Woolson and Harris 1983, Paavilainen et al. 1993, Jasty et al. 1995, Hartofilakidis et al. 1998, Anderson and Harris 1999, Hartofilakidis and Karachalios 2004, Perka et al. 2004).

#### 10.2.2.8 Previous tuberculous coxarthritis

In this study (V), there were three patients who previously had tuberculosis of the hip. All were treated with a shortening osteotomy of the femur and transposition of the greater trochanter. Two of these hips required splitting of the femoral shaft both anteriorly and posteriorly to facilitate insertion of the smallest sized stem. None of these patients had either wound infection or reactivation of the tuberculosis. It has been reported previously, that the risk of recurrence of tuberculosis is low in such patients (Kim et al. 2001, Yoon et al. 2005).

#### 10.2.2.9 Leg-lengthening

Adequate lengthening of the leg is important, especially for the patients with unilateral dislocation of the hip joint. Functional lengthening is limited by tight soft tissues and especially by the sciatic nerve. In many patients, it is difficult to estimate the optimal amount of lengthening. The method of shortening the proximal femur combined with distal advancement of the greater trochanter allows functional lengthening up to 5 cm in cases with untreated high dislocation, but in the cases after Schanz osteotomy, it is limited according to the level of the Schanz angulation. If insufficient lengthening is obtained by this method, segmental shortening osteotomy combined with angular correction is performed. With the latter method, functional lengthening of up to 3–4 cm is possible. The choice between these two operation methods is always made preoperatively. The younger the patient, then the greater the effort to achieve equal length. Patients with fixed degenerative changes of the low back must be carefully tested preoperatively with various elevations (Hoikka et al. 1993).

#### 10.2.2.10 Summary

In adult patients with severely dysplastic hips, independent of the aetiology of the hip disease, uncemented THA with distal advancement of the greater trochanter, femoral shortening osteotomy, and soft-tissue releases can substantially reduce pain and improve hip joint function. For the patients with low-seated unilateral

Schanz osteotomy, subtrochanteric segmental resection and angular correction is recommended because it gives better correction of the leg length. In the present study (IV and V), these techniques combined with anatomical placement of the cup led to an increase in the abduction strength, as most of the patients walked without a limp, had good active abduction strength, and displayed a negative Trendelenburg sign. Aseptic loosening of the threaded uncemented cups was common. Additionally, press-fit, porous-coated uncemented acetabular components had good fixation, but excessive wear of the PE liner and periacetabular osteolysis resulted in numerous revisions. Revision of the uncemented porous-coated CDH stem for aseptic loosening was uncommon, and there were no radiographical signs of loosening around these stems in the mid- to long-term follow-up.

# 11. CONCLUSIONS

1. Uncemented proximally circumferentially porous- and HA-coated stem design concepts provided young patients with primary OA with good long-term outcomes. On the other hand survival of modern uncemented cup concepts was no better than that of the all-poly cemented cup concept in these patients.
2. Modern second-generation uncemented stem designs, especially the Biomet Bi-Metric, had good long-term survival in young patients with primary OA. However, survival rates of uncemented cup designs were unsatisfactorily low because of multiple liner revisions.
3. Uncemented proximally circumferentially porous-coated stems and cemented all-poly cups provided young patients with RA the best long-term results. These design concepts can be recommended for young patients with RA.
4. Uncemented THA, with placement of the cup at the level of the true acetabulum, distal advancement of the greater trochanter, and femoral shortening osteotomy can be recommended for young patients with high congenital hip dislocation, as it gives a good functional long-term outcome. The uncemented CDH stem had good long-term survival. Numerous cup revisions were secondary to sub-optimal modular design of the acetabular components used in this series.
5. Most of the patients with severely dysplastic hips and a previous Schanz osteotomy can be successfully treated with cementless THA, combined with transposition of the greater trochanter and femoral shortening osteotomy. However, the subtrochanteric segmental shortening with angular correction gave better leg length correction for the patients with a previous low-seated unilateral Schanz osteotomy. Both methods gave similar functional results.

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# 13. REFERENCES


**Ahnfelt L, Herberts P, Malchau H, Andersson GB.** Prognosis of total hip replacement. A Swedish multicenter study of 4,664 revisions. Acta Orthop Scand Suppl. 1990; 238: 1-26.

**Akesson K, Onsten I, Obrant KJ.** Periarticular bone in rheumatoid arthritis versus arthrosis. Histomorphometry in 103 hip biopsies. Acta Orthop Scand. 1994; 65: 135-8.

**Aldinger PR, Thomsen M, Mau H, Ewerbeck V, Breusch SJ.** Cementless Spotorno tapered titanium stems: excellent 10-15-year survival in 141 young patients. Acta Orthop Scand. 2003; 74: 253-8.

**Alho A, Lepisto J, Ylinen P, Paavilainen T.** Cemented Lubinus and Furlog total hip endoprosthesis: a 12-year follow-up study of 175 hips comparing the cementing technique. Arch Orthop Trauma Surg. 2000; 120: 276-80.

**Amstutz HC, Campbell P, Kossovsky N, Clarke IC.** Mechanism and clinical significance of wear debris-induced osteolysis. Clin Orthop Relat Res. 1992: 7-18.

**Anderson MJ, Harris WH.** Total hip arthroplasty with insertion of the acetabular component without cement in hips with total congenital dislocation or marked congenital dysplasia. J Bone Joint Surg Am. 1999; 81: 347-54.

**AOA.** Australian Orthopaedic Association National Joint Replacement Registry. Annual Report, Adelaide, 2004.

**Archibeck MJ, Berger RA, Jacobs JJ, Quigley LR, Gitelis S, Rosenberg AG, Galante JO.** Second-generation cementless total hip arthroplasty. Eight to eleven-year results. J Bone Joint Surg Am. 2001; 83-A: 1666-73.

**Aronson AS, Hoist L, Selvik G.** An instrument for insertion of radiopaque bone markers. Radiology. 1974; 113: 733-4.

**Ballard WT, Callaghan JJ, Sullivan PM, Johnston RC.** The results of improved cementing techniques for total hip arthroplasty in patients less than fifty years old. A ten-year follow-up study. J Bone Joint Surg Am. 1994; 76: 959-64.

**Bankston AB, Keating EM, Ranawat C, Faris PM, Ritter MA.** Comparison of polyethylene wear in machined versus molded polyethylene. Clin Orthop Relat Res. 1995: 37-43.

**Barrack RL, Folgueras A, Munn B, Tvetden D, Sharkey P.** Pelvic lysis and polyethylene wear at 5-8 years in an uncemented total hip. Clin Orthop Relat Res. 1997: 211-7.

**Barrack RL, Mulroy RD, Jr., Harris WH.** Improved cementing techniques and femoral component loosening in young patients with hip arthroplasty. A 12-year radiographic review. J Bone Joint Surg Br. 1992; 74: 385-9.

**Bartel DL, Bicknell VL, Wright TM.** The effect of conformity, thickness, and material on stresses in ultra-high molecular weight components for total joint replacement. J Bone Joint Surg Am. 1986; 68: 1041-51.

**Bauer TW, Geesink RC, Zimmerman R, McMahon JT.** Hydroxyapatite-coated femoral stems. Histological analysis of components retrieved at autopsy. J Bone Joint Surg Am. 1991; 73: 1439-52.

**Bauer TW, Stulberg BN, Ming J, Geesink RG.** Uncemented acetabular components. Histologic analysis of retrieved hydroxyapatite-coated and porous implants. J Arthroplasty. 1993; 8: 167-77.

**Benson K, Hartz AJ.** A comparison of observational studies and randomized, controlled trials. N Engl J Med. 2000; 342: 1878-86.

**Berger RA, Jacobs JJ, Quigley LR, Rosenberg AG, Galante JO.** Primary cementless acetabular reconstruction in patients younger than 50 years old. 7- to 11-year results. Clin Orthop Relat Res. 1997: 216-26.

**Blacha J.** High osteolysis and revision rate with the hydroxyapatite-coated ABG hip prostheses: 65 hips in 56 young patients followed for 5-9 years. Acta Orthop Scand. 2004; 75: 276-82.

**Bobyn JD, Jacobs JJ, Tanzer M, Urban RM, Aribindi R, Sumner DR, Turner TM, Brooks CE.** The susceptibility of smooth implant surfaces to periimplant fibrosis and migration of polyethylene wear debris. Clin Orthop Relat Res. 1995: 21-39.

**Boehler M, Knahr K, Plenk H, Jr., Walter A, Salzer M, Schreiber V.** Long-term results of uncemented alumina acetabular implants. J Bone Joint Surg Br. 1994; 76: 53-9.

**Boeree NR, Bannister GC.** Cemented total hip arthroplasty in patients younger than 50 years of age. Ten- to 18-year results. Clin Orthop Relat Res. 1993: 153-9.

**Bogoch ER, Moran EL.** Bone abnormalities in the surgical treatment of patients with rheumatoid arthritis. Clin Orthop Relat Res. 1999: 8-21.

**Bohm G, Lintner F, Auterith A, Lester DK, Zweymuller KA.** Morphometric examination of straight, tapered titanium stems: a retrieval study. Clin Orthop Relat Res. 2001: 13-24.

**Bojescul JA, Xenos JS, Callaghan JJ, Savory CG.** Results of porous-coated anatomic total hip arthroplasty without cement at fifteen years: a concise follow-up of a previous report. J Bone Joint Surg Am. 2003; 85-A: 1079-83.

**Brooker AF, Bowerman JW, Robinson RA, Riley LH, Jr.** Ectopic ossification following total hip replacement. Incidence and a method of classification. J Bone Joint Surg Am. 1973; 55: 1629-32.

**Bruce WJ, Rizkallah SM, Kwon YM, Goldberg JA, Walsh WR.** A new technique of subtrochanteric shortening in total hip arthroplasty: surgical technique and results of 9 cases. J Arthroplasty. 2000; 15: 617-26.

**Buly RL, Huo MH, Salvati E, Brien W, Bansal M.** Titanium wear debris in failed cemented total hip arthroplasty. An analysis of 71 cases. J Arthroplasty. 1992; 7: 315-23.

**Callaghan JJ, Forest EE, Olejniczak JP, Goetz DD, Johnston RC.** Charnley total hip arthroplasty in patients less than fifty years old. A twenty to twenty-five-year follow-up note. J Bone Joint Surg Am. 1998; 80: 704-14.

**Capello WN, D'Antonio JA, Feinberg JR, Manley MT.** Ten-year results with hydroxyapatite-coated total hip femoral components in patients less than fifty years old. A concise follow-up of a previous report. J Bone Joint Surg Am. 2003; 85-A: 885-9.

**Catelas I, Huk OL, Petit A, Zukor DJ, Marchand R, Yahia L.** Flow cytometric analysis of macrophage response to ceramic and polyethylene particles: effects of size, concentration, and composition. J Biomed Mater Res. 1998; 41: 600-7.

**Catelas I, Petit A, Zukor DJ, Marchand R, Yahia L, Huk OL.** Induction of macrophage apoptosis by ceramic and polyethylene particles in vitro. Biomaterials. 1999; 20: 625-30.

**Cates HE, Faris PM, Keating EM, Ritter MA.** Polyethylene wear in cemented metal-backed acetabular cups. J Bone Joint Surg Br. 1993; 75: 249-53.

**Chan KW, Felson DT, Yood RA, Walker AM.** Incidence of rheumatoid arthritis in central Massachusetts. Arthritis Rheum. 1993; 36: 1691-6.

**Chandler HP, Reineck FT, Wixson RL, McCarthy JC.** Total hip replacement in patients younger than thirty years old. A five-year follow-up study. J Bone Joint Surg Am. 1981; 63: 1426-34.

**Chareancholvanich K, Becker DA, Gustilo RB.** Treatment of congenital dislocated hip by arthroplasty with femoral shortening. Clin Orthop Relat Res. 1999a; 360: 127-35.

**Chareancholvanich K, Becker DA, Gustilo RB.** Treatment of congenital dislocated hip by arthroplasty with femoral shortening. Clin Orthop Relat Res. 1999b: 127-35.

**Charnley J.** Low Friction Arthroplasty of the Hip: Theory and Practice. Springer-Verlag. New York. 1979. 25–40 pp.

**Charnley J, Cupic Z.** The nine and ten year results of the low-friction arthroplasty of the hip. Clin Orthop Relat Res. 1973; 95: 9-25.

**Charnley J, Feagin JA.** Low-friction arthroplasty in congenital subluxation of the hip. Clin Orthop Relat Res. 1973; 91: 98-113.

**Charnley J, Ferreiraade S.** Transplantation of the Greater Trochanter in Arthroplasty of the Hip. J Bone Joint Surg Br. 1964; 46: 191-7.

**Charnley J, Halley DK.** Rate of wear in total hip replacement. Clin Orthop Relat Res. 1975: 170-9.

**Chen JH, Shih-Shyn Wu J.** Measurement of polyethylene wear - a new three-dimensional methodology. Comput Methods Programs Biomed. 2002; 68: 117-27.

**Chen PC, Mead EH, Pinto JG, Colwell CW, Jr.** Polyethylene wear debris in modular acetabular prostheses. Clin Orthop Relat Res. 1995: 44-56.

**Chiu KY, Ng TP, Tang WM, Poon KC, Ho WY, Yip D.** Charnley total hip arthroplasty in Chinese patients less than 40 years old. J Arthroplasty. 2001a; 16: 92-101.

**Chiu KY, Tang WM, Ng TP, Poon KC, Ho WY, Lee KM.** Cementless total hip arthroplasty in young Chinese patients: a comparison of 2 different prostheses. J Arthroplasty. 2001b; 16: 863-70.

**Chougle A, Hemmady MV, Hodgkinson JP.** Severity of hip dysplasia and loosening of the socket in cemented total hip replacement. A long-term follow-up. J Bone Joint Surg Br. 2005; 87: 16-20.

**Coathup MJ, Blunn GW, Flynn N, Williams C, Thomas NP.** A comparison of bone remodelling around hydroxyapatite-coated, porous-coated and grit-blasted hip replacements retrieved at post-mortem. J Bone Joint Surg Br. 2001; 83: 118-23.

**Coggon D, Kellingray S, Inskip H, Croft P, Campbell L, Cooper C.** Osteoarthritis of the hip and occupational lifting. Am J Epidemiol. 1998; 147: 523-8.

**Coleman SS.** Congenital dysplasia of the hip in the Navajo infant. Clin Orthop Relat Res. 1968; 56: 179-93.

**Collis DK.** Long-term (twelve to eighteen-year) follow-up of cemented total hip replacements in patients who were less than fifty years old. A follow-up note. J Bone Joint Surg Am. 1991; 73: 593-7.

**Colville J, Raunio P.** Charnley low-friction arthroplasties of the hip in rheumatoid arthritis. A study of the complications and results of 378 arthroplasties. J Bone Joint Surg Br. 1978; 60-B: 498-503.

**Concato J, Shah N, Horwitz RI.** Randomized, controlled trials, observational studies, and the hierarchy of research designs. N Engl J Med. 2000; 342: 1887-92.

**Cooper C, Inskip H, Croft P, Campbell L, Smith G, McLaren M, Coggon D.** Individual risk factors for hip osteoarthritis: obesity, hip injury, and physical activity. Am J Epidemiol. 1998; 147: 516-22.

**Cox DR.** Regression models and life tables. J Roy Stat Soc. 1972; 34: 187-220.

**Creighton MG, Callaghan JJ, Olejniczak JP, Johnston RC.** Total hip arthroplasty with cement in patients who have rheumatoid arthritis. A minimum ten-year follow-up study. J Bone Joint Surg Am. 1998; 80: 1439-46.

**Croft P, Coggon D, Cruddas M, Cooper C.** Osteoarthritis of the hip: an occupational disease in farmers. Bmj. 1992a; 304: 1269-72.

**Croft P, Cooper C, Wickham C, Coggon D.** Osteoarthritis of the hip and occupational activity. Scand J Work Environ Health. 1992b; 18: 59-63.

**Crowe JF, Mani VJ, Ranawat CS.** Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am. 1979; 61: 15-23.

**Danielsson L, Lindberg H.** Prevalence of coxarthrosis in an urban population during four decades. Clin Orthop Relat Res. 1997: 106-10.

**D'Antonio JA, Capello WN, Crothers OD, Jaffe WL, Manley MT.** Early clinical experience with hydroxyapatite-coated femoral implants. J Bone Joint Surg Am. 1992; 74: 995-1008.

**D'Aubigne RM, Postel M.** Function al results of hip arthroplasty with acrylic prosthesis. J Bone Joint Surg Am. 1954; 36-A: 451-75.

**Dearborn JT, Harris WH.** High placement of an acetabular component inserted without cement in a revision total hip arthroplasty. Results after a mean of ten years. J Bone Joint Surg Am. 1999; 81: 469-80.

**DeLee JG, Charnley J.** Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res. 1976: 20-32.

**Devane PA, Bourne RB, Rorabeck CH, Hardie RM, Horne JG.** Measurement of polyethylene wear in metal-backed acetabular cups. I. Three-dimensional technique. Clin Orthop Relat Res. 1995a: 303-16.

**Devane PA, Bourne RB, Rorabeck CH, MacDonald S, Robinson EJ.** Measurement of polyethylene wear in metal-backed acetabular cups. II. Clinical application. Clin Orthop Relat Res. 1995b: 317-26.

**Devitt A, O'Sullivan T, Quinlan W.** 16- to 25-year follow-up study of cemented arthroplasty of the hip in patients aged 50 years or younger. J Arthroplasty. 1997; 12: 479-89.

**DHR**, The Danish Hip Arthroplasty Register. Annual Report 2004, Århus, 2004.

**DiFazio F, Shon WY, Salvati EA, Wilson PD, Jr.** Long-term results of total hip arthroplasty with a cemented custom-designed swan-neck femoral component for congenital dislocation or severe dysplasia: a follow-up note. J Bone Joint Surg Am. 2002; 84-A: 204-7.

**Doorn PF, Campbell PA, Worrall J, Benya PD, McKellop HA, Amstutz HC.** Metal wear particle characterization from metal on metal total hip replacements: transmission electron microscopy study of periprosthetic tissues and isolated particles. J Biomed Mater Res. 1998; 42: 103-11.

**Doorn PF, Mirra JM, Campbell PA, Amstutz HC.** Tissue reaction to metal on metal total hip prostheses. Clin Orthop Relat Res. 1996: S187-205.

**Dorey FJ.** Survivorship analysis of surgical treatment of the hip in young patients. Clin Orthop Relat Res. 2004: 23-8.

**Dorlot JM, Christel P, Meunier A.** Wear analysis of retrieved alumina heads and sockets of hip prostheses. J Biomed Mater Res. 1989; 23: 299-310.

**Dorr LD, Luckett M, Conaty JP.** Total hip arthroplasties in patients younger than 45 years. A nine- to ten-year follow-up study. Clin Orthop Relat Res. 1990: 215-9.

**Dorr LD, Wan Z, Shahrdar C, Sirianni L, Boutary M, Yun A.** Clinical performance of a Durasul highly cross-linked polyethylene acetabular liner for total hip arthroplasty at five years. J Bone Joint Surg Am. 2005; 87: 1816-21.

**Dowd JE, Sychterz CJ, Young AM, Engh CA.** Characterization of long-term femoral-head-penetration rates. Association with and prediction of osteolysis. J Bone Joint Surg Am. 2000; 82-A: 1102-7.

**Dudkiewicz I, Salai M, Ganel A, Blankstein A, Chechik A.** Total hip arthroplasty in patients younger than 30 years of age following developmental dysplasia of hip (DDH) in infancy. Arch Orthop Trauma Surg. 2002; 122: 139-42.

**Duffy GP, Berry DJ, Rowland C, Cabanela ME.** Primary uncemented total hip arthroplasty in patients <40 years old: 10- to 14-year results using first-generation proximally porous-coated implants. J Arthroplasty. 2001; 16: 140-4.

**Duffy P, Sher JL, Partington PF.** Premature wear and osteolysis in an HA-coated, uncemented total hip arthroplasty. J Bone Joint Surg Br. 2004; 86: 34-8.

**Eberhardt K, Fex E, Johnsson K, Geborek P.** Hip involvement in early rheumatoid arthritis. Ann Rheum Dis. 1995; 54: 45-8.

**Eberhardt KB, Rydgren LC, Pettersson H, Wollheim FA.** Early rheumatoid arthritis--onset, course, and outcome over 2 years. Rheumatol Int. 1990; 10: 135-42.

**Eftekhar N.** Principles of total hip arthroplasty. CV Mosby. St Louis. 1978. 437-455 pp.

**Emery DF, Clarke HJ, Grover ML.** Stanmore total hip replacement in younger patients: review of a group of patients under 50 years of age at operation. J Bone Joint Surg Br. 1997; 79: 240-6.

**Engh CA, Bobyn JD, Glassman AH.** Porous-coated hip replacement. The factors governing bone ingrowth, stress shielding, and clinical results. J Bone Joint Surg Br. 1987; 69: 45-55.

**Engh CA, Griffin WL, Marx CL.** Cementless acetabular components. J Bone Joint Surg Br. 1990; 72: 53-9.

**Engh CA, Hooten JP, Jr., Zettl-Schaffer KF, Ghaffarpour M, McGovern TF, Bobyn JD.** Evaluation of bone ingrowth in proximally and extensively porous-coated anatomic medullary locking prostheses retrieved at autopsy. J Bone Joint Surg Am. 1995; 77: 903-10.

**Espehaug B, Engesaeter LB, Vollset SE, Havelin LI, Langeland N.** Antibiotic prophylaxis in total hip arthroplasty. Review of 10,905 primary cemented total hip replacements reported to the Norwegian arthroplasty register, 1987 to 1995. J Bone Joint Surg Br. 1997; 79: 590-5.

**Fehring TK, Smith SE, Braun ER, Mobley C, Wang PL, Griffin WL.** Motion at the modular acetabular shell and liner interface. A comparative study. Clin Orthop Relat Res. 1999: 306-14.

**Flugsrud GB, Nordsletten L, Espehaug B, Havelin LI, Meyer HE.** Risk factors for total hip replacement due to primary osteoarthritis: a cohort study in 50,034 persons. Arthritis Rheum. 2002; 46: 675-82.

**Furnes O, Lie SA, Espehaug B, Vollset SE, Engesaeter LB, Havelin LI.** Hip disease and the prognosis of total hip replacements. A review of 53,698 primary total hip replacements reported to the Norwegian Arthroplasty Register 1987-99. J Bone Joint Surg Br. 2001; 83: 579-86.

**Furnes O, Lie SA, Havelin LI, Vollset SE, Engesaeter LB.** Exeter and charnley arthroplasties with Boneloc or high viscosity cement. Comparison of 1,127 arthroplasties followed for 5 years in the Norwegian Arthroplasty Register. Acta Orthop Scand. 1997; 68: 515-20.

**Fye MA, Huo MH, Zatorski LE, Keggi KJ.** Total hip arthroplasty performed without cement in patients with femoral head osteonecrosis who are less than 50 years old. J Arthroplasty. 1998; 13: 876-81.

**Garvin KL, Bowen MK, Salvati EA, Ranawat CS.** Long-term results of total hip arthroplasty in congenital dislocation and dysplasia of the hip. A follow-up note. J Bone Joint Surg Am. 1991; 73: 1348-54.

**Giannikas KA, Din R, Sadiq S, Dunningham TH.** Medium-term results of the ABG total hip arthroplasty in young patients. J Arthroplasty. 2002; 17: 184-8.

**Gruen TA, McNeice GM, Amstutz HC.** "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res. 1979: 17-27.

**Hakala M, Pollanen R, Nieminen P.** The ARA 1987 revised criteria select patients with clinical rheumatoid arthritis from a population based cohort of subjects with chronic rheumatic diseases registered for drug reimbursement. J Rheumatol. 1993; 20: 1674-8.

**Hall RM, Siney P, Unsworth A, Wroblewski BM.** The association between rates of wear in retrieved acetabular components and the radius of the femoral head. Proc Inst Mech Eng [H]. 1998; 212: 321-6.

**Halley DK, Wroblewski BM.** Long-term results of low-friction arthroplasty in patients 30 years of age or younger. Clin Orthop Relat Res. 1986: 43-50.

**Hansson G, Nachemson A, Palmen K.** Screening of children with congenital dislocation of the hip joint on the maternity wards in Sweden. J Pediatr Orthop. 1983; 3: 271-9.

**Hardinge K.** The direct lateral approach to the hip. J Bone Joint Surg Br. 1982; 64: 17-9.

**Harley JM, Wilkinson JA.** Hip replacement for adults with unreduced congenital dislocation. A new surgical technique. J Bone Joint Surg Br. 1987; 69: 752-5.

**Harris WH.** Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am. 1969; 51: 737-55.

**Harris WH.** Etiology of osteoarthritis of the hip. Clin Orthop Relat Res. 1986: 20-33.

**Harris WH.** Management of the deficient acetabulum using cementless fixation without bone grafting. Orthop Clin North Am. 1993; 24: 663-5.

**Harris WH.** Wear and periprosthetic osteolysis: the problem. Clin Orthop Relat Res. 2001: 66-70.

**Harris WH.** Results of uncemented cups: a critical appraisal at 15 years. Clin Orthop Relat Res. 2003: 121-5.

**Harris WH, Crothers O, Oh I.** Total hip replacement and femoral-head bone-grafting for severe acetabular deficiency in adults. J Bone Joint Surg Am. 1977; 59: 752-9.

**Harris WH, Maloney WJ.** Hybrid total hip arthroplasty. Clin Orthop Relat Res. 1989: 21-9.

**Harris WH, Schiller AL, Scholler JM, Freiberg RA, Scott R.** Extensive localized bone resorption in the femur following total hip replacement. J Bone Joint Surg Am. 1976; 58: 612-8.

**Hartofilakidis G, Karachalios T,** Total hip replacement in congenital hip disease, Surgical techniques in orthopaedics and traumatology, Elsevier, Paris, 2000.

**Hartofilakidis G, Karachalios T.** Total hip arthroplasty for congenital hip disease. J Bone Joint Surg Am. 2004; 86-A: 242-50.

**Hartofilakidis G, Karachalios T, Stamos KG.** Epidemiology, demographics, and natural history of congenital hip disease in adults. Orthopedics. 2000; 23: 823-7.

**Hartofilakidis G, Stamos K, Karachalios T.** Treatment of high dislocation of the hip in adults with total hip arthroplasty. Operative technique and long-term clinical results. J Bone Joint Surg Am. 1998; 80: 510-7.

**Hartofilakidis G, Stamos K, Karachalios T, Ioannidis TT, Zacharakis N.** Congenital hip disease in adults. Classification of acetabular deficiencies and operative treatment with acetabuloplasty combined with total hip arthroplasty. J Bone Joint Surg Am. 1996; 78: 683-92.

**Hass J.** Newer trends in the treatment of old congenital dislocations of the hip. J Int Coll Surg. 1953; 20: 667-81.

**Havelin LI, Engesaeter LB, Espehaug B, Furnes O, Lie SA, Vollset SE.** The Norwegian Arthroplasty Register: 11 years and 73,000 arthroplasties. Acta Orthop Scand. 2000; 71: 337-53.

**Havelin LI, Espehaug B, Vollset SE, Engesaeter LB.** Early aseptic loosening of uncemented femoral components in primary total hip replacement. A review based on the Norwegian Arthroplasty Register. J Bone Joint Surg Br. 1995a; 77: 11-7.

**Havelin LI, Espehaug B, Vollset SE, Engesaeter LB.** The effect of the type of cement on early revision of Charnley total hip prostheses. A review of eight thousand five hundred and seventy-nine primary arthroplasties from the Norwegian Arthroplasty Register. J Bone Joint Surg Am. 1995b; 77: 1543-50.

**Havelin LI, Espehaug B, Vollset SE, Engesaeter LB, Langeland N.** The Norwegian arthroplasty register. A survey of 17,444 hip replacements 1987-1990. Acta Orthop Scand. 1993; 64: 245-51.

**Havelin LI, Gjerdet NR, Lunde OD, Rait M, Sudmann E.** Wear of the Christiansen hip prosthesis. Acta Orthop Scand. 1986; 57: 419-22.

**Havelin LI, Vollset SE, Engesaeter LB.** Revision for aseptic loosening of uncemented cups in 4,352 primary total hip prostheses. A report from the Norwegian Arthroplasty Register. Acta Orthop Scand. 1995c; 66: 494-500.

**Hazes JM, Silman AJ.** Review of UK data on the rheumatic diseases--2. Rheumatoid arthritis. Br J Rheumatol. 1990; 29: 310-2.

**Heekin RD, Callaghan JJ, Hopkinson WJ, Savory CG, Xenos JS.** The porous-coated anatomic total hip prosthesis, inserted without cement. Results after five to seven years in a prospective study. J Bone Joint Surg Am. 1993; 75: 77-91.

**Herberts P, Malchau H.** Long-term registration has improved the quality of hip replacement: a review of the Swedish THR Register comparing 160,000 cases. Acta Orthop Scand. 2000; 71: 111-21.

**Hess WE, Umber JS.** Total hip arthroplasty in chronically dislocated hips. Follow-up study on the protrusio socket technique. J Bone Joint Surg Am. 1978; 60: 948-54.

**Hirakawa K, Bauer TW, Hashimoto Y, Stulberg BN, Wilde AH, Secic M.** Effect of femoral head diameter on tissue concentration of wear debris. J Biomed Mater Res. 1997; 36: 529-35.

**Hirakawa K, Bauer TW, Stulberg BN, Wilde AH.** Comparison and quantitation of wear debris of failed total hip and total knee arthroplasty. J Biomed Mater Res. 1996a; 31: 257-63.

**Hirakawa K, Bauer TW, Stulberg BN, Wilde AH, Secic M.** Characterization and comparison of wear debris from failed total hip implants of different types. J Bone Joint Surg Am. 1996b; 78: 1235-43.

**Hoikka V, Paavilainen T, Santavirta S, Eskola A, Tallroth K, Lindholm TS.** Leg length inequality in replacement of dysplastic or dislocated hips. Int Orthop. 1993; 1: 160-5.

**Hozack WJ, Rothman RH.** Long-term survival of the Charnley low-friction total hip arthroplasty. Semin Arthroplasty. 1990; 1: 3-6.

**Huk OL, Bansal M, Betts F, Rimnac CM, Lieberman JR, Huo MH, Salvati EA.** Polyethylene and metal debris generated by non-articulating surfaces of modular acetabular components. J Bone Joint Surg Br. 1994; 76: 568-74.

**Huskisson EC.** Measurement of pain. Lancet. 1974; 2: 1127-31.

**Ilchmann T.** Radiographic assessment of cup migration and wear after hip replacement. Acta Orthop Scand Suppl. 1997; 276: 1-26.

**Inman V.** Functional aspects of the abductor muscles of the hip. J Bone Joint Surg Am. 1947; 29: 607.

**Jacobsen S, Jensen FK, Poulsen K, Sturup J, Retpen JB.** Good performance of a titanium femoral component in cementless hip arthroplasty in younger patients: 97 arthroplasties followed for 5-11 years. Acta Orthop Scand. 2003; 74: 375-9.

**Jasty M, Anderson MJ, Harris WH.** Total hip replacement for developmental dysplasia of the hip. Clin Orthop Relat Res. 1995: 40-5.

**Jasty M, Goetz DD, Bragdon CR, Lee KR, Hanson AE, Elder JR, Harris WH.** Wear of polyethylene acetabular components in total hip arthroplasty. An analysis of one hundred and twenty-eight components retrieved at autopsy or revision operations. J Bone Joint Surg Am. 1997; 79: 349-58.

**Johnston RC, Fitzgerald RH, Jr., Harris WH, Poss R, Muller ME, Sledge CB.** Clinical and radiographic evaluation of total hip replacement. A standard system of terminology for reporting results. J Bone Joint Surg Am. 1990; 72: 161-8.

**Joshi AB, Porter ML, Trail IA, Hunt LP, Murphy JC, Hardinge K.** Long-term results of Charnley low-friction arthroplasty in young patients. J Bone Joint Surg Br. 1993; 75: 616-23.

**Kaipiainen-Seppanen O, Aho K, Isomaki H, Laakso M.** Incidence of rheumatoid arthritis in Finland during 1980-1990. Ann Rheum Dis. 1996; 55: 608-11.

**Kaplan E, Meier P.** Nonparametric estimation from incomplete observations. J Am Stat Assoc. 1958; 53: 457-81.

**Karachalios T, Hartofilakidis G, Zacharakis N, Tsekoura M.** A 12- to 18-year radiographic follow-up study of Charnley low-friction arthroplasty. The role of the center of rotation. Clin Orthop Relat Res. 1993: 140-7.

**Kärrholm J.** Retrospective evaluation of implants - Is there a need? Acta Orthop Scand. 2003; 74: 1-3.

**Katsimihas M, Taylor AH, Lee MB, Sarangi PP, Learmonth ID.** Cementless acetabular replacement in patients with rheumatoid arthritis: a 6- to 14-year prospective study. J Arthroplasty. 2003; 18: 16-22.

**Kavanagh BF, Fitzgerald RH, Jr.** Clinical and roentgenographic assessment of total hip arthroplasty. A new hip score. Clin Orthop Relat Res. 1985: 133-40.

**Kawate K, Maloney WJ, Bragdon CR, Biggs SA, Jasty M, Harris WH.** Importance of a thin cement mantle. Autopsy studies of eight hips. Clin Orthop Relat Res. 1998: 70-6.

**Keener JD, Callaghan JJ, Goetz DD, Pederson DR, Sullivan PM, Johnston RC.** Twenty-five-year results after Charnley total hip arthroplasty in patients less than fifty years old: a concise follow-up of a previous report. J Bone Joint Surg Am. 2003; 85-A: 1066-72.

**Keisu KS, Orozco F, McCallum JD, 3rd, Bissett G, Hozack WJ, Sharkey PF, Rothman RH.** Cementless femoral fixation in the rheumatoid patient undergoing total hip arthroplasty: minimum 5-year results. J Arthroplasty. 2001; 16: 415-21.

**Kennedy JG, Rogers WB, Soffe KE, Sullivan RJ, Griffen DG, Sheehan LJ.** Effect of acetabular component orientation on recurrent dislocation, pelvic osteolysis, polyethylene wear, and component migration. J Arthroplasty. 1998; 13: 530-4.

**Kesteris U, Ilchmann T, Wingstrand H, Onnerfalt R.** Polyethylene wear in Scanhip arthroplasty with a 22 or 32 mm head: 62 matched patients followed for 7-9 years. Acta Orthop Scand. 1996; 67: 125-7.

**Kim SY, Kyung HS, Ihn JC, Cho MR, Koo KH, Kim CY.** Cementless Metasul metal-on-metal total hip arthroplasty in patients less than fifty years old. J Bone Joint Surg Am. 2004; 86-A: 2475-81.

**Kim YH, Kim JS, Oh SH, Kim JM.** Comparison of porous-coated titanium femoral stems with and without hydroxyapatite coating. J Bone Joint Surg Am. 2003a; 85-A: 1682-8.

**Kim YH, Kook HK, Kim JS.** Total hip replacement with a cementless acetabular component and a cemented femoral component in patients younger than fifty years of age. J Bone Joint Surg Am. 2002; 84-A: 770-4.

**Kim YH, Oh SH, Kim JS.** Primary total hip arthroplasty with a second-generation cementless total hip prosthesis in patients younger than fifty years of age. J Bone Joint Surg Am. 2003b; 85-A: 109-14.

**Kim YY, Ahn JY, Sung YB, Ko CU, Shim JC, Park HS, Bai GH.** Long-term results of Charnley low-friction arthroplasty in tuberculosis of the hip. J Arthroplasty. 2001; 16: 106-10.

**Kirk PG, Rorabeck CH, Bourne RB, Burkart B.** Total hip arthroplasty in rheumatoid arthritis: comparison of cemented and uncemented implants. Can J Surg. 1993; 36: 229-32.

**Kivilaakso R.** The Schanz osteotomy for irreducible dislocation of the hip; a clinical study with an evaluation of results based on the follow-up of 100 cases. Ann Chir Gynaecol Fenn. 1959; 48: 1-41.

**Klapach AS, Callaghan JJ, Miller KA, Goetz DD, Sullivan PM, Pedersen DR, Johnston RC.** Total Hip Arthroplasty with Cement and without Acetabular Bone Graft for Severe Hip Dysplasia. A Concise Follow-Up, At a Minimum of Twenty Years, of a Previous Report. J Bone Joint Surg Am. 2005; 87: 280-285.

**Kobayashi S, Eftekhar NS, Terayama K, Joshi RP.** Comparative study of total hip arthroplasty between younger and older patients. Clin Orthop Relat Res. 1997: 140-51.

**Konttinen YT, Santavirta S, Waris V,** Reumapotilaiden tekonivelkirurgia Suomessa 1980-1998, 2000.

**Konttinen YT, Zhao D, Beklen A, Ma G, Takagi M, Kivela-Rajamaki M, Ashammakhi N, Santavirta S.** The microenvironment around total hip replacement prostheses. Clin Orthop Relat Res. 2005: 28-38.

**Krismer M, Bauer R, Tschupik J, Mayrhofer P.** EBRA: a method to measure migration of acetabular components. J Biomech. 1995; 28: 1225-36.

**Kurtz SM, Muratoglu OK, Evans M, Edidin AA.** Advances in the processing, sterilization, and crosslinking of ultra-high molecular weight polyethylene for total joint arthroplasty. Biomaterials. 1999a; 20: 1659-88.

**Kurtz SM, Ochoa JA, Hovey CB, White CV.** Simulation of initial frontside and backside wear rates in a modular acetabular component with multiple screw holes. J Biomech. 1999b; 32: 967-76.

**Kurtz SM, Ochoa JA, White CV, Srivastav S, Cournoyer J.** Backside nonconformity and locking restraints affect liner/shell load transfer mechanisms and relative motion in modular acetabular components for total hip replacement. J Biomech. 1998; 31: 431-7.

**Lachiewicz PF, McCaskill B, Inglis A, Ranawat CS, Rosenstein BD.** Total hip arthroplasty in juvenile rheumatoid arthritis. Two to eleven-year results. J Bone Joint Surg Am. 1986; 68: 502-8.

**Lai K-A, Shen W-J, Huang L-W, Chen M-Y.** Cementless Total Hip Arthroplasty and Limb-Length Equalization in Patients with Unilateral Crowe Type-IV Hip Dislocation. J Bone Joint Surg Am. 2005; 87: 339-345.

**Lane NE, Lin P, Christiansen L, Gore LR, Williams EN, Hochberg MC, Nevitt MC.** Association of mild acetabular dysplasia with an increased risk of incident hip osteoarthritis in elderly white women: the study of osteoporotic fractures. Arthritis Rheum. 2000; 43: 400-4.

**Lanyon P, Muir K, Doherty S, Doherty M.** Assessment of a genetic contribution to osteoarthritis of the hip: sibling study. Bmj. 2000; 321: 1179-83.

**Lawrence RC, Helmick CG, Arnett FC, Deyo RA, Felson DT, Giannini EH, Heyse SP, Hirsch R, Hochberg MC, Hunder GG, Liang MH, Pillemer SR, Steen VD, Wolfe F.** Estimates of the prevalence of arthritis and selected musculoskeletal disorders in the United States. Arthritis Rheum. 1998; 41: 778-99.

**Lee PC, Shih CH, Chen WJ, Tu YK, Tai CL.** Early polyethylene wear and osteolysis in cementless total hip arthroplasty: the influence of femoral head size and polyethylene thickness. J Arthroplasty. 1999; 14: 976-81.

**Lehtimaki MY, Kaarela K, Hamalainen MM.** Incidence of hip involvement and need for total hip replacement in rheumatoid arthritis. An eight-year follow-up study. Scand J Rheumatol. 1986; 15: 387-91.

**Lehtimaki MY, Kautiainen H, Hamalainen MM, Lehto MU, Ikavalko M, Repo AB, Kotaniemi HA, Kaarela K.** Hip involvement in seropositive rheumatoid arthritis. Survivorship analysis with a 15-year follow-up. Scand J Rheumatol. 1998; 27: 406-9.

**Lehtimaki MY, Kautiainen H, Lehto UK, Hamalainen MM.** Charnley low-friction arthroplasty in rheumatoid patients: a survival study up to 20 years. J Arthroplasty. 1999; 14: 657-61.

**Lehtimaki MY, Lehto MU, Kautiainen H, Savolainen HA, Hamalainen MM.** Survivorship of the Charnley total hip arthroplasty in juvenile chronic arthritis. A follow-up of 186 cases for 22 years. J Bone Joint Surg Br. 1997; 79: 792-5.

**Lewis G.** Polyethylene wear in total hip and knee arthroplasties. J Biomed Mater Res. 1997; 38: 55-75.

**Lie SA, Engesaeter LB, Havelin LI, Gjessing HK, Vollset SE.** Mortality after total hip replacement: 0-10-year follow-up of 39,543 patients in the Norwegian Arthroplasty Register. Acta Orthop Scand. 2000; 71: 19-27.

**Lievense AM, Bierma-Zeinstra SM, Verhagen AP, Verhaar JA, Koes BW.** Influence of hip dysplasia on the development of osteoarthritis of the hip. Ann Rheum Dis. 2004; 63: 621-6.

**Lindberg H, Roos H, Gardsell P.** Prevalence of coxarthrosis in former soccer players. 286 players compared with matched controls. Acta Orthop Scand. 1993; 64: 165-7.

**Linde F, Jensen J, Pilgaard S.** Charnley arthroplasty in osteoarthritis secondary to congenital dislocation or subluxation of the hip. Clin Orthop Relat Res. 1988; 227: 164-71.

**Livermore J, Ilstrup D, Morrey B.** Effect of femoral head size on wear of the polyethylene acetabular component. J Bone Joint Surg Am. 1990; 72: 518-28.

**Lombardi AV, Jr., Mallory TH, Dennis DA, Komistek RD, Fada RA, Northcut EJ.** An in vivo determination of total hip arthroplasty pistoning during activity. J Arthroplasty. 2000; 15: 702-9.

**Lucht U.** The Danish Hip Arthroplasty Register. Acta Orthop Scand. 2000; 71: 433-9.

**Lund KH, Termansen NB.** Hip replacement for congenital dislocation and dysplasia. Acta Orthop Scand. 1985; 56: 464-8.

**Lyback CC, Lyback CO, Kyro A, Kautiainen HJ, Belt EA.** Survival of Bi-Metric femoral stems in 77 total hip arthroplasties for juvenile chronic arthritis. Int Orthop. 2004; 28: 357-61.

**Malchau H, Herberts P, Ahnfelt L.** Prognosis of total hip replacement in Sweden. Follow-up of 92,675 operations performed 1978-1990. Acta Orthop Scand. 1993; 64: 497-506.

**Malchau H, Herberts P, Eisler T, Garellick G, Soderman P.** The Swedish Total Hip Replacement Register. J Bone Joint Surg Am. 2002; 84-A Suppl 2: 2-20.

**Malchau H, Herberts P, Wang YX, Karrholm J, Romanus B.** Long-term clinical and radiological results of the Lord total hip prosthesis. A prospective study. J Bone Joint Surg Br. 1996; 78: 884-91.

**Malchau H, Wang YX, Karrholm J, Herberts P.** Scandinavian multicenter porous coated anatomic total hip arthroplasty study. Clinical and radiographic results with 7- to 10-year follow-up evaluation. J Arthroplasty. 1997; 12: 133-48.

**Malcolm A,** Cemented and Hydroxyapatite-Coated Hip Implants: An Autopsy Retrieval Study. In: B Morrey (Ed.), Biological, Material, and Mechanical Considerations of Joint Replacement, Raven Press, New York, 1993, pp. 39–50.

**Mallory TH.** Total hip replacement with and without trochanteric osteotomy. Clin Orthop Relat Res. 1974; 0: 133-5.

**Maloney WJ, Jasty M, Burke DW, O'Connor DO, Zalenski EB, Bragdon C, Harris WH.** Biomechanical and histologic investigation of cemented total hip arthroplasties. A study of autopsy-retrieved femurs after in vivo cycling. Clin Orthop Relat Res. 1989: 129-40.

**Masonis JL, Patel JV, Miu A, Bourne RB, McCalden R, Macdonald SJ, Rorabeck CH.** Subtrochanteric shortening and derotational osteotomy in primary total hip arthroplasty for patients with severe hip dysplasia: 5-year follow-up. J Arthroplasty. 2003; 18: 68-73.

**McKellop H, Park SH, Chiesa R, Doorn P, Lu B, Normand P, Grigoris P, Amstutz H.** In vivo wear of three types of metal on metal hip prostheses during two decades of use. Clin Orthop Relat Res. 1996: S128-40.

**McKellop H, Shen FW, DiMaio W, Lancaster JG.** Wear of gamma-crosslinked polyethylene acetabular cups against roughened femoral balls. Clin Orthop Relat Res. 1999: 73-82.

**McKellop HA, Campbell P, Park SH, Schmalzried TP, Grigoris P, Amstutz HC, Sarmiento A.** The origin of submicron polyethylene wear debris in total hip arthroplasty. Clin Orthop Relat Res. 1995: 3-20.

**McLaughlin JR, Lee KR.** Total hip arthroplasty in young patients. 8- to 13-year results using an uncemented stem. Clin Orthop Relat Res. 2000: 153-63.

**Mittelmeier H, Heisel J.** Sixteen-years' experience with ceramic hip prostheses. Clin Orthop Relat Res. 1992: 64-72.

**Mjoberg B.** Theories of wear and loosening in hip prostheses. Wear-induced loosening vs loosening-induced wear--a review. Acta Orthop Scand. 1994; 65: 361-71.

**Morscher E,** Total hip replacement for osteoarthritis in congenital hip dysplasia. In: P Castelyn, J Duparc and P Fulford (Eds.), European instructional course lectures, Vol. 2, The British Editorial Society of Bone and Joint Surgery, London, 1995.

**Morscher EW.** Current status of acetabular fixation in primary total hip arthroplasty. Clin Orthop Relat Res. 1992: 172-93.

**Mottonen T, Hannonen P, Leirisalo-Repo M, Nissila M, Kautiainen H, Korpela M, Laasonen L, Julkunen H, Luukkainen R, Vuori K, Paimela L, Blafield H, Hakala M, Ilva K, Yli-Kerttula U, Puolakka K, Jarvinen P, Hakola M, Piirainen H, Ahonen J, Palvimaki I, Forsberg S, Koota K, Friman C.** Comparison of combination therapy with single-drug therapy in early rheumatoid arthritis: a randomised trial. FIN-RACo trial group. Lancet. 1999a; 353: 1568-73.

**Mottonen TT, Hannonen PJ, Boers M.** Combination DMARD therapy including corticosteroids in early rheumatoid arthritis. Clin Exp Rheumatol. 1999b; 17: S59-65.

**Mulroy RD, Jr., Harris WH.** Failure of acetabular autogenous grafts in total hip arthroplasty. Increasing incidence: a follow-up note. J Bone Joint Surg Am. 1990; 72: 1536-40.

**Muratoglu OK, Bragdon CR, O'Connor D, Perinchief RS, Estok DM, 2nd, Jasty M, Harris WH.** Larger diameter femoral heads used in conjunction with a highly crosslinked ultra-high molecular weight polyethylene: a new concept. J Arthroplasty. 2001a; 16: 24-30.

**Muratoglu OK, Bragdon CR, O'Connor DO, Jasty M, Harris WH.** A novel method of cross-linking ultra-high-molecular-weight polyethylene to improve wear, reduce oxidation, and retain mechanical properties. Recipient of the 1999 HAP Paul Award. J Arthroplasty. 2001b; 16: 149-60.

**NAR**. The Norwegian Arthroplasty Register. Annual Report 2005, 2005.

**Nasser S, Campbell PA, Kilgus D, Kossovsky N, Amstutz HC.** Cementless total joint arthroplasty prostheses with titanium-alloy articular surfaces. A human retrieval analysis. Clin Orthop Relat Res. 1990: 171-85.

**Neumann L, Freund KG, Sorensen KH.** Total hip arthroplasty with the Charnley prosthesis in patients fifty-five years old and less. Fifteen to twenty-one-year results. J Bone Joint Surg Am. 1996; 78: 73-9.

**Nevalainen J**, The 2002-2003 Implant Yearbook on Orthopaedic Endoprostheses. Finnish Arthroplasty Register., 2004.

**NICE.** Guidance on the Selection of prostheses for primary total hip replacement. London. 2003.

**Niinimaki T, Puranen J, Jalovaara P.** Total hip arthroplasty using isoelastic femoral stems. A seven- to nine-year follow-up in 108 patients. J Bone Joint Surg Br. 1994; 76: 413-8.

**Ohlin A, Selvik G.** Socket wear assessment. A comparison of three different radiographic methods. J Arthroplasty. 1993; 8: 427-31.

**Oliveria SA, Felson DT, Cirillo PA, Reed JI, Walker AM.** Body weight, body mass index, and incident symptomatic osteoarthritis of the hand, hip, and knee. Epidemiology. 1999; 10: 161-6.

**Oosterbos CJ, Rahmy AI, Tonino AJ, Witpeerd W.** High survival rate of hydroxyapatite-coated hip prostheses: 100 consecutive hips followed for 10 years. Acta Orthop Scand. 2004; 75: 127-33.

**Orishimo KF, Claus AM, Sychterz CJ, Engh CA.** Relationship between polyethylene wear and osteolysis in hips with a second-generation porous-coated cementless cup after seven years of follow-up. J Bone Joint Surg Am. 2003; 85-A: 1095-9.

**Ostendorf M, Johnell O, Malchau H, Dhert WJ, Schrijvers AJ, Verbout AJ.** The epidemiology of total hip replacement in The Netherlands and Sweden: present status and future needs. Acta Orthop Scand. 2002; 73: 282-6.

**Paavilainen T.** Total hip replacement for developmental dysplasia of the hip. Acta Orthop Scand. 1997; 68: 77-84.

**Paavilainen T, Hoikka V, Paavolainen P.** Cementless total hip arthroplasty for congenitally dislocated or dysplastic hips. Technique for replacement with a straight femoral component. Clin Orthop Relat Res. 1993: 71-81.

**Paavilainen T, Hoikka V, Solonen KA.** Cementless total replacement for severely dysplastic or dislocated hips. J Bone Joint Surg Br. 1990; 72: 205-11.

**Paavolainen P, Hamalainen M, Mustonen H, Slatis P.** Registration of arthroplasties in Finland. A nationwide prospective project. Acta Orthop Scand Suppl. 1991; 241: 27-30.

**Paavolainen P, Pukkala E, Pulkkinen P, Visuri T.** Causes of death after total hip arthroplasty: a nationwide cohort study with 24,638 patients. J Arthroplasty. 2002; 17: 274-81.

**Pagnano W, Hanssen AD, Lewallen DG, Shaughnessy WJ.** The effect of superior placement of the acetabular component on the rate of loosening after total hip arthroplasty. J Bone Joint Surg Am. 1996; 78: 1004-14.

**Park YS, Lee JY, Yun SH, Jung MW, Oh I.** Comparison of hydroxyapatite- and porous-coated stems in total hip replacement. Acta Orthop Scand. 2003; 74: 259-63.

**Park YS, Moon YW, Lim SJ, Yang JM, Ahn G, Choi YL.** Early osteolysis following second-generation metal-on-metal hip replacement. J Bone Joint Surg Am. 2005; 87: 1515-21.

**Perka C, Fischer U, Taylor WR, Matziolis G.** Developmental hip dysplasia treated with total hip arthroplasty with a straight stem and a threaded cup. J Bone Joint Surg Am. 2004; 86-A: 312-9.

**Perka C, Thomas R, Zippel H.** Subtrochanteric corrective osteotomy for the endoprosthetic treatment of high hip dislocation. Treatment and mid-term results with a cementless straight stem. Arch Orthop Trauma Surg. 2000; 120: 144-8.

**Pilliar RM, Lee JM, Maniatopoulos C.** Observations on the effect of movement on bone ingrowth into porous-surfaced implants. Clin Orthop Relat Res. 1986: 108-13.

**Poss R, Maloney JP, Ewald FC, Thomas WH, Batte NJ, Hartness C, Sledge CB.** Six- to 11-year results of total hip arthroplasty in rheumatoid arthritis. Clin Orthop Relat Res. 1984: 109-16.

**Premnath V, Harris WH, Jasty M, Merrill EW.** Gamma sterilization of UHMWPE articular implants: an analysis of the oxidation problem. Ultra High Molecular Weight Poly Ethylene. Biomaterials. 1996; 17: 1741-53.

**Puolakka TJ, Laine HJ, Moilanen TP, Koivisto AM, Pajamaki KJ.** Alarming wear of the first-generation polyethylene liner of the cementless porous-coated Biomet Universal cup: 107 hips followed for mean 6 years. Acta Orthop Scand. 2001a; 72: 1-7.

**Puolakka TJ, Pajamaki KJ, Halonen PJ, Pulkkinen PO, Paavolainen P, Nevalainen JK.** The Finnish Arthroplasty Register: report of the hip register. Acta Orthop Scand. 2001b; 72: 433-41.

**Puolakka TJ, Pajamaki KJ, Pulkkinen PO, Nevalainen JK.** Poor survival of cementless Biomet total hip: a report on 1,047 hips from the Finnish Arthroplasty Register. Acta Orthop Scand. 1999; 70: 425-9.

**Ranawat CS, Dorr LD, Inglis AE.** Total hip arthroplasty in protrusio acetabuli of rheumatoid arthritis. J Bone Joint Surg Am. 1980; 62: 1059-65.

**Ries MD, Scott ML, Jani S.** Relationship between gravimetric wear and particle generation in hip simulators: conventional compared with cross-linked polyethylene. J Bone Joint Surg Am. 2001; 83-A Suppl 2 Pt 2: 116-22.

**Ritter MA, Meding JB, Faris PM, Keating EM.** Femoral head size: variation among manufacturers. Orthopedics. 1996; 19: 877-8.

**Russe W.** [Roentgen photogrammetry of the artificial hip joint acetabulum]. Aktuelle Probl Chir Orthop. 1988; 32: 1-80.

**Russotti GM, Harris WH.** Proximal placement of the acetabular component in total hip arthroplasty. A long-term follow-up study. J Bone Joint Surg Am. 1991; 73: 587-92.

**Ryöppy S,** Lonkka ja reisi, Lastenortopedia, Duodecim, Helsinki, 1997, pp. 89-95.

**Sakalkale DP, Sharkey PF, Eng K, Hozack WJ, Rothman RH.** Effect of femoral component offset on polyethylene wear in total hip arthroplasty. Clin Orthop Relat Res. 2001: 125-34.

**Santavirta S, Xu JW, Hietanen J, Ceponis A, Sorsa T, Kontio R, Konttinen YT.** Activation of periprosthetic connective tissue in aseptic loosening of total hip replacements. Clin Orthop Relat Res. 1998: 16-24.

**Schanz A.** Zur Behandlung der veralteten angeborenen Huftverrankung. Munch Med Wochenschr. 1922; 69: 930.

**Schmalzried TP, Harris WH.** The Harris-Galante porous-coated acetabular component with screw fixation. Radiographic analysis of eighty-three primary hip replacements at a minimum of five years. J Bone Joint Surg Am. 1992; 74: 1130-9.

**Schmalzried TP, Harris WH.** Hybrid total hip replacement. A 6.5-year follow-up study. J Bone Joint Surg Br. 1993; 75: 608-15.

**Schmalzried TP, Jasty M, Harris WH.** Periprosthetic bone loss in total hip arthroplasty. Polyethylene wear debris and the concept of the effective joint space. J Bone Joint Surg Am. 1992a; 74: 849-63.

**Schmalzried TP, Kwong LM, Jasty M, Sedlacek RC, Haire TC, O'Connor DO, Bragdon CR, Kabo JM, Malcolm AJ, Harris WH.** The mechanism of loosening of cemented acetabular components in total hip arthroplasty. Analysis of specimens retrieved at autopsy. Clin Orthop Relat Res. 1992b: 60-78.

**Schmalzried TP, Shepherd EF, Dorey FJ, Jackson WO, dela Rosa M, Fa'vae F, McKellop HA, McClung CD, Martell J, Moreland JR, Amstutz HC.** The John Charnley Award. Wear is a function of use, not time. Clin Orthop Relat Res. 2000: 36-46.

**Schmidt M, Weber H, Schon R.** Cobalt chromium molybdenum metal combination for modular hip prostheses. Clin Orthop Relat Res. 1996: S35-47.

**Schramm M, Keck F, Hohmann D, Pitto RP.** Total hip arthroplasty using an uncemented femoral component with taper design: outcome at 10-year follow-up. Arch Orthop Trauma Surg. 2000; 120: 407-12.

**Schulte KR, Callaghan JJ, Kelley SS, Johnston RC.** The outcome of Charnley total hip arthroplasty with cement after a minimum twenty-year follow-up. The results of one surgeon. J Bone Joint Surg Am. 1993; 75: 961-75.

**Schwend RM, Pratt WB, Fultz J.** Untreated acetabular dysplasia of the hip in the Navajo. A 34 year case series followup. Clin Orthop Relat Res. 1999: 108-16.

**Scott DL, Campbell PA, McClung CD, Schmalzried TP.** Factors contributing to rapid wear and osteolysis in hips with modular acetabular bearings made of hylamer. J Arthroplasty. 2000; 15: 35-46.

**Seddon H, editor.** Peripheral Nerve Injuries. Medical Research Counsil Special Report Series No. 282. London: Her Majesty's Stationery Office; 1954.

**Sener N, Tozun IR, Asik M.** Femoral shortening and cementless arthroplasty in high congenital dislocation of the hip. J Arthroplasty. 2002; 17: 41-8.

**Sharp DJ, Porter KM.** The Charnley total hip arthroplasty in patients under age 40. Clin Orthop Relat Res. 1985: 51-6.

**Shih CH, Lee PC, Chen JH, Tai CL, Chen LF, Wu JS, Chang WH.** Measurement of polyethylene wear in cementless total hip arthroplasty. J Bone Joint Surg Br. 1997; 79: 361-5.

**Simank HG, Brocai DR, Reiser D, Thomsen M, Sabo D, Lukoschek M.** Middle-term results of threaded acetabular cups. High failure rates five years after surgery. J Bone Joint Surg Br. 1997; 79: 366-70.

**Smith SE, Estok DM, 2nd, Harris WH.** 20-year experience with cemented primary and conversion total hip arthroplasty using so-called second-generation cementing techniques in patients aged 50 years or younger. J Arthroplasty. 2000; 15: 263-73.

**Sochart DH.** Relationship of acetabular wear to osteolysis and loosening in total hip arthroplasty. Clin Orthop Relat Res. 1999: 135-50.

**Sochart DH, Porter ML.** The long-term results of Charnley low-friction arthroplasty in young patients who have congenital dislocation, degenerative osteoarthrosis, or rheumatoid arthritis. J Bone Joint Surg Am. 1997a; 79: 1599-617.

**Sochart DH, Porter ML.** Long-term results of total hip replacement in young patients who had ankylosing spondylitis. Eighteen to thirty-year results with survivorship analysis. J Bone Joint Surg Am. 1997b; 79: 1181-9.

**Sochart DH, Porter ML.** Long-term results of cemented Charnley low-friction arthroplasty in patients aged less than 30 years. J Arthroplasty. 1998; 13: 123-31.

**SOS**. The Swedish National Arthroplasty Register. Annual Report 2004, 2005.

**Stans AA, Pagnano MW, Shaughnessy WJ, Hanssen AD.** Results of total hip arthroplasty for Crowe Type III developmental hip dysplasia. Clin Orthop Relat Res. 1998: 149-57.

**Sullivan PM, MacKenzie JR, Callaghan JJ, Johnston RC.** Total hip arthroplasty with cement in patients who are less than fifty years old. A sixteen to twenty-two-year follow-up study. J Bone Joint Surg Am. 1994; 76: 863-9.

**Sumner DR, Jasty M, Jacobs JJ, Urban RM, Bragdon CR, Harris WH, Galante JO.** Histology of porous-coated acetabular components. 25 cementless cups retrieved after arthroplasty. Acta Orthop Scand. 1993; 64: 619-26.

**Sychterz CJ, Moon KH, Hashimoto Y, Terefenko KM, Engh CA, Jr., Bauer TW.** Wear of polyethylene cups in total hip arthroplasty. A study of specimens retrieved post mortem. J Bone Joint Surg Am. 1996; 78: 1193-200.

**Sychterz CJ, Yang AM, McAuley JP, Engh CA.** Two-dimensional versus three-dimensional radiographic measurements of polyethylene wear. Clin Orthop Relat Res. 1999: 117-23.

**Tallroth K, Slatis P, Ylinen P, Paavolainen P, Paavilainen T.** Loosening of threaded acetabular components. Radiographic manifestations. J Arthroplasty. 1993; 8: 581-4.

**Tanner MG, Whiteside LA, White SE.** Effect of polyethylene quality on wear in total knee arthroplasty. Clin Orthop Relat Res. 1995: 83-8.

**Thanner J, Karrholm J, Malchau H, Herberts P.** Poor outcome of the PCA and Harris-Galante hip prostheses. Randomized study of 171 arthroplasties with 9-year follow-up. Acta Orthop Scand. 1999; 70: 155-62.

**Tonino A, Oosterbos C, Rahmy A, Therin M, Doyle C.** Hydroxyapatite-coated acetabular components. Histological and histomorphometric analysis of six cups retrieved at

autopsy between three and seven years after successful implantation. J Bone Joint Surg Am. 2001; 83-A: 817-25.

**Tonino AJ, Rahmy AI.** The hydroxyapatite-ABG hip system: 5- to 7-year results from an international multicentre study. The International ABG Study Group. J Arthroplasty. 2000; 15: 274-82.

**Tonino AJ, Therin M, Doyle C.** Hydroxyapatite-coated femoral stems. Histology and histomorphometry around five components retrieved at post mortem. J Bone Joint Surg Br. 1999; 81: 148-54.

**Tronzo RG, Okin EM.** Anatomic restoration of congenital hip dysplasia in adulthood by total hip displacement. Clin Orthop Relat Res. 1975: 94-8.

**Turula KB, Friberg O, Haajanen J, Lindholm TS, Tallroth K.** Weight-bearing radiography in total hip replacement. Skeletal Radiol. 1985; 14: 200-4.

**Vingard E, Alfredsson L, Goldie I, Hogstedt C.** Occupation and osteoarthrosis of the hip and knee: a register-based cohort study. Int J Epidemiol. 1991; 20: 1025-31.

**Vingard E, Alfredsson L, Goldie I, Hogstedt C.** Sports and osteoarthrosis of the hip. An epidemiologic study. Am J Sports Med. 1993; 21: 195-200.

**Visuri T, Pukkala E, Paavolainen P, Pulkkinen P, Riska EB.** Cancer risk after metal on metal and polyethylene on metal total hip arthroplasty. Clin Orthop Relat Res. 1996: S280-9.

**von Schewelov T, Sanzen L, Onsten I, Carlsson A.** Catastrophic failure of an uncemented acetabular component due to high wear and osteolysis: an analysis of 154 omnifit prostheses with mean 6-year follow-up. Acta Orthop Scand. 2004; 75: 283-94.

**Wang ML, Sharkey PF, Tuan RS.** Particle bioreactivity and wear-mediated osteolysis. J Arthroplasty. 2004; 19: 1028-38.

**Wedge JH, Wasylenko MJ.** The natural history of congenital dislocation of the hip: a critical review. Clin Orthop Relat Res. 1978: 154-62.

**Weinstein S,** Developmental hip dysplasia and dislocation. In: R Morrissy and S Weinstein (Eds.), Lovell and Winter's pediatric orthopaedics, Vol. 2, Lippincott Williams and Wilkins, Philadelphia, 2001, pp. 905-56.

**Weinstein SL.** Natural history of congenital hip dislocation (CDH) and hip dysplasia. Clin Orthop Relat Res. 1987: 62-76.

**Weinstein SL, Mubarak SJ, Wenger DR.** Developmental hip dysplasia and dislocation: Part II. Instr Course Lect. 2004; 53: 531-42.

**White SH.** The fate of cemented total hip arthroplasty in young patients. Clin Orthop Relat Res. 1988: 29-34.

**Wiles N, Symmons DP, Harrison B, Barrett E, Barrett JH, Scott DG, Silman AJ.** Estimating the incidence of rheumatoid arthritis: trying to hit a moving target? Arthritis Rheum. 1999; 42: 1339-46.

**Wilkinson JM, Hamer AJ, Stockley I, Eastell R.** Polyethylene wear rate and osteolysis: critical threshold versus continuous dose-response relationship. J Orthop Res. 2005; 23: 520-5.

**Williams VG, 2nd, Whiteside LA, White SE, McCarthy DS.** Fixation of ultrahigh-molecular-weight polyethylene liners to metal-backed acetabular cups. J Arthroplasty. 1997; 12: 25-31.

**Wolfgang GL.** Femoral head autografting with total hip arthroplasty for lateral acetabular dysplasia. A 12-year experience. Clin Orthop Relat Res. 1990: 173-85.

**Woolson ST, Harris WH.** Complex total hip replacement for dysplastic or hypoplastic hips using miniature or microminiature components. J Bone Joint Surg Am. 1983; 65: 1099-108.

**Wroblewski BM.** 15-21-year results of the Charnley low-friction arthroplasty. Clin Orthop Relat Res. 1986: 30-5.

**Wroblewski BM, Fleming PA, Hall RM, Siney PD.** Stem fixation in the Charnley low-friction arthroplasty in young patients using an intramedullary bone block. J Bone Joint Surg Br. 1998; 80: 273-8.

**Wroblewski BM, Siney PD.** Charnley low-friction arthroplasty in the young patient. Clin Orthop Relat Res. 1992: 45-7.

**Wymenga AB, van Horn JR, Theeuwes A, Muytjens HL, Slooff TJ.** Perioperative factors associated with septic arthritis after arthroplasty. Prospective multicenter study

of 362 knee and 2,651 hip operations. Acta Orthop Scand. 1992; 63: 665-71.

**Yamaguchi M, Bauer TW, Hashimoto Y.** Three-dimensional analysis of multiple wear vectors in retrieved acetabular cups. J Bone Joint Surg Am. 1997; 79: 1539-44.

**Yasgur DJ, Stuchin SA, Adler EM, DiCesare PE.** Subtrochanteric femoral shortening osteotomy in total hip arthroplasty for high-riding developmental dislocation of the hip. J Arthroplasty. 1997; 12: 880-8.

**Yoder SA, Brand RA, Pedersen DR, O'Gorman TW.** Total hip acetabular component position affects component loosening rates. Clin Orthop Relat Res. 1988: 79-87.

**Yoon TR, Rowe SM, Jung ST, Seon KJ, Maloney WJ.** Osteolysis in association with a total hip arthroplasty with ceramic bearing surfaces. J Bone Joint Surg Am. 1998; 80: 1459-68.

**Yoon TR, Rowe SM, Santosa SB, Jung ST, Seon JK.** Immediate cementless total hip arthroplasty for the treatment of active tuberculosis. J Arthroplasty. 2005; 20: 923-6.

**Young AM, Sychterz CJ, Hopper RH, Jr., Engh CA.** Effect of acetabular modularity on polyethylene wear and osteolysis in total hip arthroplasty. J Bone Joint Surg Am. 2002; 84-A: 58-63.