Total knee arthroplasty
Aspects on improved fixation in the younger patient

Av

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PAPERS

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals

I.
Nilsson KG, Henricson A, Norgren B, Dalén T.
Uncemented HA-coated implant is the optimum fixation for the TKA in the young patient.

II.
Henricson A, Dalén T, Nilsson KG.
Mobile bearings do not improve fixation in cemented total knee arthroplasty.

III.
Henricson A, Linder L, Nilsson KG.
Trabecular metal tibial component in patients younger than 60 years. A prospective RSA study.
Submitted 2008.

IV.
Gao F, Henricson A, Nilsson KG.
### ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>MBK</td>
<td>Mobile Bearing Knee</td>
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<tr>
<td>NG</td>
<td>Nex Gen</td>
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<tr>
<td>NG CR</td>
<td>NexGen Cruciate Retaining</td>
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<tr>
<td>OA</td>
<td>Osteoarthrosis</td>
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<tr>
<td>PE</td>
<td>Polyethylene</td>
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<tr>
<td>PMMA</td>
<td>Polymethyl-methacrylate (= bone cement)</td>
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<tr>
<td>RSA</td>
<td>RadioStereometric Analysis</td>
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<tr>
<td>RA</td>
<td>Rheumatoid Arthritis</td>
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<td>SKAR</td>
<td>The Swedish Knee Arthroplasty Register</td>
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<tr>
<td>TM</td>
<td>Trabecular Metal</td>
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<td>TM CR</td>
<td>Trabecular Metal Cruciate Retaining</td>
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<td>TMT</td>
<td>Trabecular Metal Tibia</td>
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<td>TKA</td>
<td>Total Knee Arthroplasty</td>
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INTRODUCTION

History and development of total knee arthroplasty

Treatment of osteoarthrosis of the knee with total knee arthroplasty is an established and reliable method. The first modern type of total knee replacement was designed by Gluck, who in 1890 presented a concept of surface replacing with the use of ivory components attached to the bone with a cement made of colophony, pumice and plaster of Paris. However, neither the ivory nor the cement could withstand the forces applied to the knee and infection became a major problem.

The modern era of total knee replacement began with Gunston (1971) who, influenced by the work of Charnley, in 1968 designed a surface replacing prosthesis with a metal component articulating against a polyethylene component and both components attached to the bone with bone cement made of polymethyl-methacrylate (PMMA). The design was an unicompartmental prosthesis suited for either the medial or the lateral compartment or both. Freeman and Swanson (1972) designed an unlinked total knee prosthesis of condylar type and inserted the first one in 1970. Modifications of this design is still in clinical use as the Freeman-Samuelson prosthesis. Insall worked with the same concept, and 1973 the Total Condylar Knee was introduced (Insall et al. 1976a). This was a semiconstrained prosthesis with the femoral component made of metal and the tibial component of polyethylene. The femoral component had an anterior flange for articulation against a polyethylene patellar component. The tibial component was cup-shaped for stability, had an intercondylar eminence and an intramedullary peg to enhance fixation. All components were cemented. Short-term good results were reported 1979 (Insall et al.).
This concept is still considered to be “the gold standard” of total knee arthroplasty.

Despite reasonably good results in the late 1970s, the failure rates in knee arthroplasty were higher than in hip arthroplasty (Tew and Waugh 1982). The major cause for failure was loosening of components, especially on the tibial side (Moreland 1988). Biomechanical studies indicated that a metal reinforcement of the polyethylene tibial component would lead to lower and more evenly distributed stresses to the underlying bone and thus improved fixation (Bartel et al. 1982, Reilly et al. 1982, Lewis et al. 1982). The designs of total knee prostheses during the 1980s were therefore changed to metal-backed tibial components and also to less conforming articular surfaces in order to decrease forces acting on the implant-bone interface.

Despite improved results, there were still some problems. The most common reason for revision during the 1980s was still component loosening (Knutson et al. 1994). Several reports of negative effects of the bone cement such as heat injury (Mjöberg 1986) and chemical toxicity (Stürup et al. 1994) resulting in bone resorption and osteolytic activity (Fornasier et al. 1991, Schmalzried et al. 1992, Bos et al. 1995) led to a search for alternative fixation methods. Uncemented designs were developed as press-fit implants either of polyethylene (Blaha et al. 1982) or with metal backing coated with porous layers in order to achieve bony ongrowth or ingrowth (Hungerford et al. 1989) often enhanced with screw fixation (Rosenberg et al. 1990). Although good results were reported with uncemented implants (Hofmann et al. 2001), no superiority to cemented designs could be detected (McCaskie et al. 1998). RadioStereometric Analysis (RSA) investigations revealed no differences in migration between cemented and uncemented implants in some studies (Nilsson et al. 1991, Toksvig-Larsen et al. 1998), but showed increased tilting of uncemented components in others (Nilsson and Kärrholm 1993). In fact,
some authors found higher revision rates with uncemented prostheses (Robertsson et al. 1997, Duffy et al. 1998, Berger et al. 2001b) and Lachiewitz (2001) stated that cemented total knee arthroplasty is the gold standard. Therefore, a turning back to cemented concepts ensued. Further development of designs in order to improve fixation of the components came about. The concept of mobile bearing total knee arthroplasty, which theoretically would uncouple the forces acting on the implant-bone interface and thus improve fixation was developed early (Goodfellow and O’Connor 1986, Buechel and Pappas 1986) and good results have been reported (Buechel 2004, Callaghan et al. 2005, Tarkin et al. 2005). Coating the porous layer at the undersurface of components with hydroxy-apatite (HA) have been shown to enhance fixation of implant to bone (Regnér et al. 1998, Önsten et al. 1998, Nelissen et al. 1998, Toksvig-Larsen et al. 2000). Novel material for implant coating have been developed i.e. trabecular metal (Bobyn et al. 1999a).

In general, the results of total knee arthroplasty in long-term reports are very good with prosthetic survival rates of 92–99 % at 14–17 years (Font-Rodriquez et al. 1997, Gill and Joshi 2001, Keating et al. 2002). The increasing need of total knee arthroplasty in younger patients (Laskin 2002) and the higher revision rates in these patients (Furnes et al. 2002, Harrysson et al. 2004) constitutes the challenge today to develop concepts of knee replacement that will have a longevity of at least 25 years. To my knowledge there are no randomized studies and indeed no high resolution (as RSA) studies in the literature concerning younger patients. This thesis will investigate various factors that potentially may improve the results of TKA in younger patients.
Factors related to prosthetic fixation

Patient related factors

Age

The prevalence of osteoarthrosis is increasing in patients in their 50s and 60s presumably as a result from a change of life-style with more physically demanding leisure-time activities and organized sports activities leading to more injuries to the anterior cruciate ligament, the menisci and the articular surfaces (Laskin 2002). This increase of osteoarthrosis is in turn leading to an increasing need and demand for total knee replacement (Robertsson et al. 2000, Laskin 2002, Ritter 2002). The life-style with higher activity level in this age group will inevitably put higher stresses to the implants and to implant fixation. The challenge today is therefore to design TKAs with a longevity of 25 years or more.

The results of TKA in younger patients are varying. Many reports show good results (Dalury et al. 1995, Gill et al. 1997, Hofmann et al. 2002, Morgan et al. 2007, Whiteside and Viganò 2007) but they involve relative small numbers of patients, have mid-term follow-ups and mixed diagnoses making it hard to draw any extensive conclusions. In long-term follow-ups of patients with OA Diduch et al. (1997) and Duffy et al. (2007) present 10-year survival rates of 94-96 % concerning revision for loosening of components. However, Duffy et al. (2007) had several revisions due to wear and osteolysis in the second decade leading to a decreased survivalship of 85 % at 15 years. Crowder et al. (2005), in patients with RA younger than 55 years, reported a 94 % survival rate at 20 years. In larger cohorts, the results of TKA in younger patients are inferior. Gill and Joshi (2001) found, in a long term study of cemented TKAs, a revision rate in patients younger than 55 years of 21 % compared to 3 % in patients older than 55 years. Gioe et al. (2007) report from a community register in patients younger than 55 years with knee replacement
of different designs a 14-year survival rate of 74.5% compared to 85% for the cemented TKAs. The large Scandinavian knee arthroplasty registers show significantly higher revision rates in younger patients (Robertsson et al. 2001, Furnes et al. 2002). When comparing 1,434 patients aged below 60 years with 21,761 patients aged 60 years or more Harrysson et al. (2004) found a more than twice as high revision rate in the younger patient group. Analysing loosening of components as the cause of revision, the rate was 6% for the younger group and 2.5% for the elder group.

It seems as if patients younger than 55 to 60 years have higher revision rates than the elderly patients. The main problem is obviously component loosening and thus fixation of components to bone. Studies of implants with presumably more reliable concepts of fixation in younger patients are therefore desirable. To my knowledge there are no reports in the literature of randomized studies of such TKAs in patients younger than 60 to 65 years.

**Diagnosis**

OA (osteoarthritis) or RA (rheumatoid arthritis). The incidence of total knee arthroplasty in Sweden is 10 times higher in OA patients than in RA patients (Robertsson et al. 2000). RA patients generally receive a total knee arthroplasty at younger age (mean 7 years) than do patients with OA (Robertsson et al. 2001). RA patients have an inferior bone quality compared to OA patients, which presumably would affect the results after total knee arthroplasty negatively. However, RA patients have a more sedentary way of living with lower activity level. Weir et al. (1996) found, in a 12-year follow-up, no difference in survivorship of knee replacement between OA or RA. On the other hand did Gill and Joshi (2001) find a better prognosis in OA than in RA in a 10-year follow-up. In a study of a large cohort (more
than 11,000 knees), Rand et al. (2003) found a significantly lower revision rate for RA patients which corroborates the findings of the Swedish Knee Arthroplasty Register (SKAR) (Robertsson et al. 2001). In SKAR, OA patients had a 1.3 times higher risk for revision than RA patients. The risk of infection is, however, higher in RA patients (Moreland 1988, Robertsson et al. 2001). In patients younger than 55 years Ritter et al. (2007) found lower revision rate in RA patients than in OA patients.

RA patients, who often are younger than OA patients, seem to have better results than OA patients. There are few reports concerning patients younger than 60 to 65 years and no randomized studies dealing with differences between the diagnoses.

Weight
The definition of obesity is when the body mass index (BMI) is greater than 30. Morbid obesity is present when the BMI is over 40. The incidence of obesity is slowly increasing in western countries and thus more obese patients are being considered for total knee arthroplasty. The higher stresses put on an implant carrying higher weight are assumed to result in more wear and loosening of components.

In a large long-term follow-up study the success rate of TKA was not influenced by weight (Font-Rodriques et al. 1997). Spicer et al. (2001) found similar 10-year survivalship for both obese and non-obese patients. Focal osteolysis was, however, more common in the morbidly obese. Comparing a group of obese patients with a matched group of non-obese patients Foran et al. (2004a) demonstrated lower Knee Society Score for any degree of obesity and a higher revision rate in the morbidly obese. The same research group (Foran et al. 2004b) found a higher failure rate in obese patients after TKA,
but this did not become apparent until after 14 years, which strongly emphasizes the need for long-term follow-ups in joint replacement surgery. The postoperative infection rate in highly obese (BMI>35) patients was 6.7 times higher after knee arthroplasty according to Namba et al. (2005). A lower Knee Society Score, a higher incidence of radiolucent lines, a higher rate of complications (infection, deep-vein thrombosis) and an inferior survivorship in morbidly obese patients with knee arthroplasty was found by Amin et al. (2006). Krushell and Fingeroth (2007) found higher rates of wound complications, suboptimal alignment and late revision in morbidly obese patients.

The risk of complication and inferior result after total knee arthroplasty seems higher in obese patients, especially in the morbidly obese. Therefore it is recommendable to advise obese patients to lose weight prior to TKA (and then keep it) in order to minimize detrimental complications. In randomized studies you are trying to avoid outliers due to extreme inclusion values and therefore it is common to set an upper limit of weight. No specific studies of younger obese patients have been found in the literature.

**Gender**

The male to female ratio among patients receiving a TKA is 1:2 in patients with primary OA and 1:3 in RA patients (Robertsson et al. 2001). Several studies have shown no influence of gender concerning revision rates (Font-Rodriques et al. 1997, Gill and Joshi 2001). In SKAR there was no difference in OA patients, but a higher revision risk for men in RA patients (Robertsson et al. 2001). Rand et al. (2003) found inferior overall survivorship at ten years for men. Women generally have more pain and disability prior to surgery and
also greater disability after TKA, but report postoperative global health scores (i.e. SF-36) similar to men (Hawker et al. 1998).

Prosthesis factors

The tibial component

In the beginning of the modern era of total knee replacement the tibial component was made of all-polyethylene and fixed to the bone by bone cement (PMMA) (Gunstone 1971, Freeman and Swanson 1972, Insall 1976a). In these early TKAs the articular surfaces were highly conforming. Total knee arthroplasty is fully conforming when the radii of the femoral and the tibial components are identical. The greater the radius of the tibial component articular surface, the less conforming becomes the TKA. High conformity enhances the stability of the joint and produces a large area of contact between the components when loaded (Colizza et al. 1995). A large contact area means less point pressure and less intermittent eccentric loading of the polyethylene component and thus decreased risk of polyethylene wear. The disadvantage of this design is the constraint of the construction leading to transfer of the rotational and translational forces of the articulation to the implant-bone interfaces and hence loosening of components (Werner et al. 1978). Low conforming TKAs are less constrained allowing more rotational and sliding movements at the articulation with kinematics more similar the normal knee. The disadvantage is a risk for eccentric loading of the tibial component with small areas of high pressure leading to stress of the interface and an increased risk of polyethylene wear (Bartel et al. 1982). The optimum degree of conformity is not known and the tendency in modern TKAs is a moderately conforming articulation.
Lower stresses to the cancellous bone beneath the tibial component when the component was reinforced with a metal tray was found in a finite-element study by Bartel et al. (1982). Lewis et al. (1982), also using a finite-model analysis, showed that the lowest stresses to the cement-bone interface were found in a single-post, metal-backed tibial component. A cadaver study gave the same result with lower interface shearing forces beneath metal-backed tibial components than beneath polyethylene components (Reilly et al. 1982). These reports together with the problem of loosening of the tibial components (Moreland 1988) led to a change to metal-backed tibial components. Furthermore, metal-backed components could act as a heat sink (Mjöberg 1986) and lower the temperature during cement polymerisation, which presumably would decrease the thermal necroses in bone and thereby reduce the fibrous tissue layer. Other proposed advantages with metal-backing was the ability to add stems, wedges and blocks and the concept of modularity, which facilitated exchange of the polyethylene insert in case of instability or polyethylene wear without having to remove the entire tibial component from the bone.

In searching for reasons of component loosening in TKA many researchers focused on the bone cement (PMMA) and its properties. Histologic studies of stable implants revealed increased osteoclastic activity in the vicinity of the fibrous membrane at the implant-bone interface (Fornasier et al. 1991), evidence of bone resorption at the implant-bone interface (Schmalzried et al. 1992), and histiocytic infiltration in the cancellous bone adjacent to the fibrous membrane (Bos et al. 1995). Toxic effects of bone cement on bone perfusion and remodelling were found in a canine study by Stürup et al. (1994). Negative effects on bone tissue from the heat emerging from the cement when curing was shown by Mjöberg (1986).
The condition “cement disease” was proposed by Jones and Hungerford (1987) and in order to avoid any detrimental effects of bone cement, experiments with porous materials coated on metal started. With sintered fiber titanium composites Galante et al. (1971) showed bony ingrowth already after 2 weeks in rabbit and dog femora. They concluded that a fiber metal composite bonded to a solid metal core would provide fixation to bone and uniform stress distribution at the implant-bone interface. The concept with porous coating of implants, with the assumption of increased longevity and thus more suited for younger patients, became widely used either as sintered fibers or sintered beads of metal, and showed promising results in short-term follow-ups (Hungerford et al. 1989, Dodd et al. 1990). Additional effects of uncemented replacements are shortened operating time and an improved possibility to retain the components in case of infection, because there is no avascular implant-bone interface (Cross and Parrish 2005). A higher revision rate in uncemented TKAs compared to cemented TKAs was reported by Duffy et al. (1998), Rand et al. (2003) and Cloke et al. (2008). Reviewing several reports of uncemented knee prostheses Lachiewics (2001) found significantly higher rate of component loosening and osteolysis compared to cemented concepts and stated that a cemented tricompartmental arthroplasty remained the gold standard. However, excellent long-term results with prosthetic survival of 98-99 % at 18-20 years was reported by Buechel et al. (2001) and Whiteside (2001) using cementless prostheses. Concerning younger patients operated with uncemented knee arthroplasty Hofmann et al. (2002), in a study of patients younger than 50 years with mid-term follow-up, found good clinical results and no revision for loosening of components. Long-term follow-up studies have shown increased incidence of failures with uncemented TKAs in patients younger than 55 years (Gioe et
al. 2007) and 60 years (Cloke et al. 2008), respectively. In several randomized studies have no differences between cemented and uncemented TKAs been revealed concerning clinical parameters (Nilsson et al. 1991, Nilsson and Kärrholm 1993, Önsten et al. 1998, McCaskie et al. 1998).

The prerequisite for bony ingrowth is initial stability and it was shown that uncemented tibial baseplates secured with four cancellous screws had the greatest initial stability (Voltz et al. 1988, Lee et al. 1991). Securing the tibial tray with screws was also found to achieve the highest extent of bony ingrowth compared to trays with pegs but without screws (Sumner et al. 1994). This concept became widely spread and screw fixation of the tibial component was considered “the gold standard” in uncemented fixation. However, screw fixation turned out to be associated with osteolysis around the screws and the screw holes. In mid-term studies, osteolysis around the screws were found in 16-22% of cementless tibial trays (Peters et al. 1992, Lewis et al. 1995, Goldberg and Kraay 2004). In a long-term follow-up study, finding a rate of tibial component aseptic loosening of 8% and 12% incidence of osteolytic lesions, Berger et al. (2001b) stated that they have abandoned cementless fixation. Nevertheless, some studies with screw-fixated uncemented tibial components have revealed good results. Watanabe et al. (2004) showed a 97 % survival at 13 years and Whiteside and Viganò (2007) found no loosening of components in a mid-term follow-up of patients younger than 55 years.

Covering the porous coating in cementless prostheses with hydroxy-apatite (HA) by a plasma spray technique has proved to enhance the ability of bony ongrowth in implants (Søballe et al. 1999). The positive effect of HA coating on implant-bone fixation works in both stable and unstable mechanical situations. Furthermore, it was found that bone growth across a gap was enhanced by HA and thus HA coating had a capacity of sealing defects
(Rahbek et al. 2000). One retrieved HA-coated tibial component two years postoperatively was examined histio-morphometrically by Akizuki et al. (2003) and the tissue within the porous coating of the tray and the pegs were bone in 81 %. The interface consisted of 78 % bone, 21 % marrow and 1 % fibrous tissue. Several randomized studies using RSA have shown superior results of HA coated implants compared to non-HA coated porous or fiber mesh coated implants or to cemented implants. Migration was less in HA coated fiber mesh tibial trays compared to a fiber mesh coated tray with no HA in studies by Regnér et al. (1998) and Nelissen et al. (1998). When comparing the migration of cemented tibial implants with HA coated implants, Toksvig-Larsen et al. (2000) found a strong positive effect of the HA coating on the fixation of the tibial component. Several randomized RSA studies with 5-year follow-up have been published. Nilsson et al. (1999) showed that the magnitude of migration did not differ between uncemented HA coated and cemented tibial implants. However, the pattern of migration differed, the HA coated implants displayed most of the migration within the initial 3 months and then stabilized, while the cemented implants continued to slowly migrate over time. Comparing HA coated tibial trays with porous coated trays, Regnér et al. (2000) found less migration and less inducible displacements of the HA coated implants. The patients in the study by Önsten et al. (1998) were evaluated 5 years postoperatively (Carlsson et al. 2005) and the magnitude of migration was less for cemented tibial implants compared to HA coated implants, however, the HA coated implants stabilized within 6 months while the cemented implants showed continuous migration.

There are few long-term reports of HA coated prostheses. A prospective analysis of 1429 knees followed a mean of 6.6 years revealed only one revision for aseptic loosening and a 10-year survival rate of 99% (Cross and
Parish 2005). In a later analysis of 118 knees in patients younger than 55 years they found 2 aseptic loosenings of the tibial component and an overall 12-year survival of 92% (Tai and Cross 2006).

New materials for uncemented fixation have been developed. Trabecular metal has several theoretical advantages (Bobyn et al. 1999a, Zhang et al. 1999, Florio et al. 2004) that will be thoroughly discussed in a separate chapter in this thesis.

In general, it seems that uncemented concepts are afflicted with problems leading to inferior results, especially in younger patients. Coating the implants with HA, however, seems to enhance the quality of implant-bone fixation leading to improved results in both clinical follow-ups and RSA studies. Few reports are found concerning younger patients with HA coated implants and none using the RSA technique. Whether screw fixation of tibial base plates results in improved fixation has not been the object of any RSA study in younger patients. There are only sparse short-term reports of trabecular metal tibial implants and no study in younger patients.

The femoral component

Aseptic loosening of the femoral component is less frequent than of the tibial component, but nevertheless a problem. In a multicenter cohort of revised TKAs Mulhall et al. (2006) reported that femoral component loosening constituted one third of the TKAs that were revised because of loosening. The authors did not specifically state whether the components were cemented or uncemented. Other reports in the literature have come to different conclusions.

Concerning cemented femoral components long-term follow-ups revealed no loosenings at all (Schai et al. 1998, Berger et al. 2001a). Keating et al. (2002) found a revision rate of the femoral component of 0.18% compared to
0.46% of the tibial component. In mid-term studies of cemented femoral components, Chockalingam and Scott (2000) and Lachiewicz and Soileau (2006) found very few loosenings.

Uncemented femoral components have performed very well with no loosenings in long-term studies by Schröder et al. (2001), Berger et al. (2001b) and Whiteside (2001). On the other hand Campbell et al. (1998) and Chockalingam and Scott (2000) found pronounced problems in mid-term follow-ups with revision rates of uncemented femoral components of 9-10%. Goldberg and Kraay (2004) found 17% femoral osteolysis in a long-term follow-up. Occasional femoral loosening in a long-term study has been reported by Tarkin et al. (2005).

HA coating of the femoral component has proved successful with no femoral loosenings in a mid-term study by Cross and Parish (2005) and in a long-term study concerning patients younger than 55 years (Tai and Cross 2006). Only two studies of femoral component fixation using RSA are found in the literature. Nilsson et al. (1995) studied the Miller-Galante I prosthesis and found no difference in migration between cemented and uncemented implants at 2 years follow-up. Uvehammer et al. (2007) used the Freeman-Samuelsson prosthesis of three different designs randomized to receive either a cemented or a HA coated femoral component and found that the rotations around the three cardinal axes did not differ between the different modes of fixation.

The optimum mode of fixation of the femoral component seems unclear. Almost all earlier studies of femoral component fixation are done in elderly patients. To my knowledge there are no randomized studies of femoral fixation in younger patients.
Mobile bearing TKA

A successful total knee arthroplasty should fulfil three important criteria; freedom of pain, stability and mobility. Movements of the normal knee include not only flexion and extention, but also rotations around the other two cardinal axes and translations along all three cardinal axes. In order to reduce polyethylene wear, improve the kinematics of the artificial knee and lower the risk of tibial component loosening, Goodfellow and O’Connor (1986) developed a tibio-femoral artificial joint with a meniscal bearing (mobile bearing TKA), which was first implanted 1976. This design consists of a convex spherical metal femoral component and a flat metal tibial component. Free meniscal bearings of polyethylene are placed between the metallic components. The bearings are spherically concave above, flat below, and held in place by their geometry. They can rotate and slide at the tibio-meniscal articulation, and the menisco-femoral articulation is fully conforming. This implant was designed as an unicompartmental knee replacement. This concept of mobile bearing TKA was soon followed by others. Bicompartmental mobile bearing TKA with two meniscal bearings medially and laterally was introduced 1977 by Buechel and Pappas (1986). A mobile bearing TKA with one meniscal bearing covering the entire tibial plateau was also developed by Buechel and Pappas (1986). Different designs of mobile bearings offer different mobility of the bearing, some designs only rotate, others rotate and have some anterior-posterior translation, and some are unconstrained.

The kinematics of a normal knee includes posterior femoral roll-back of the lateral condyle and internal axial rotation during flexion (Komistek et al. 2003). Studies with in vivo fluoroscopic examinations of different fixed
bearing TKAs have shown reductions of the posterior femoral roll-back and axial rotation, femoral condylar lift-off, reversed axial rotational patterns and even a paradoxical anterior femoral translation during deep flexion (Dennis and Komistek 2006). Normal rotation is needed for optimal patellar tracking and optimal flexion in the knee. In mobile bearing total knee arthroplasty the paradoxical anterior femoral translation is reduced (Dennis 2005). In a kinematic study, D’Lima et al. (2000) found that the normal tibial rotation during extension was significantly changed in a fixed bearing total knee arthroplasty, while a mobile rotating meniscal bearing TKA had minimal effect on tibio-femoral kinematics. The main rotational motion occurs at the inferior aspect of the mobile bearing with minimal motion between the femoral component and the polyethylene insert (Komistek et al. 2004). This pattern theoretically uncouples the forces at the interface between the tibial component and the bone and thereby reduces the risk for aseptic loosening. The compressive strain in the proximal tibia during axial loading and rotation was reduced by 68-73% in a mobile bearing TKA compared to a fixed bearing TKA, suggesting a more stable implant-bone interface of the mobile bearing concept (Bottlang et al. 2006). The contact stress of a mobile bearing implant is substantially lower than in a fixed bearing implant, both experimentally (Tsakonas and Polyzoides 1997, Matsuda et al. 1998, Stukenborg-Colsman et al. 2002) and in vivo (Sharma et al. 2007). Wear rates of meniscal bearings have been shown to be very low compared to fixed bearings (Tsakonas and Polyzoides 1997) and annual penetration rates lower than those of the Charnley hip have been found by Argenson and O’Connor (1992) and Psychoyios et al. (1998).

The ability to move and thus the ability of self-adjustment of the mobile bearing in order to improve the kinematics of the artificial knee have been under debate. Movements of mobile bearings in vivo have been
demonstrated by Stiehl et al. (1997), Fantozzi et al. (2002) and Hansson et al. (2005). No decrease in magnitudes of rotation of mobile bearings between 3 and 15 months was found by Komistek et al. (2004) indicating that soft tissue scarring and encapsulation of the bearing did not occur.

Follow-ups of mobile bearing TKAs have shown similar clinical results as fixed bearing TKAs. Survival rates of 90-98% at 12-20 years with only occasional aseptic loosenings of the tibial component have been reported by Buechel (2004), Sorrells et al. (2004), Callaghan et al. (2005), and Tarkin et al. (2005). In a cohort of young patients (mean 51 years) Morgan et al. (2007) found excellent clinical results and no aseptic loosening using a mobile bearing TKA in a mid-term study. In a randomized short-term study by Aglietti et al. (2005) no clinical differences between fixed or mobile bearing total knee arthroplasty were found. There is only one randomized study with mobile bearing TKA using RSA (Hansson et al. 2005). The authors found no differences between an uncemented mobile bearing TKA and an uncemented fixed bearing TKA regarding clinical results, migration or inducible displacement at 2 years follow-up.

The results of mobile bearing TKA are similar to the results of fixed bearing TKA. There is no evidence of superiority of the mobile bearing concept despite theoretical advantages. To my knowledge there is no randomized study published comparing a cemented mobile bearing TKA with a cemented fixed bearing TKA using high-resolution technique.

**Trabecular metal**

Tantalum (Ta) has been in clinical use since before 1940. The most common applications have been as radiographic marker (Ta powder), for example in the lungs or in the brain, as vascular clips and stents, and as repair of cranial
defects. Ta is quite chemically stable, oxidizing in air at 300 °C, and has an excellent corrosion resistance, being attacked only by strong acids and alkalis (Black 1994). When implanted as foil, wire, rod or ball in bone, there is significant evidence that it can become osteointegrated. Matsumo et al. (2001) implanted tantalum wires into subcutaneous tissue and into bone marrow in rats and found good biocompatibility and osteoconductivity. In the subcutaneous tissue, there was no inflammatory response and no detectable dissolution of the metal. Histological examination of the bone tissue showed slightly decreased amount of bone formation from the second to the fourth week, but signs of maturation of the bone were more evident at 4 weeks than at 2 weeks. Over the same period, a markedly increasing percentage of bone in contact with the implant were found.

Porous tantalum (trabecular metal) is manufactured by thermal reduction of a polyurethane foam precursor to form a low-density vitreous carbon skeleton which has a repeating dodecahedron array of pores. Pure tantalum is deposited into and around the carbon skeleton using chemical vapour deposition and infiltration to create a porous metal construct. The typical thickness of the tantalum coating is 50 µm. The volume porosity is 75 % to 80 %, which is 2-3 fold greater than conventional porous materials and close to the porosity of trabecular bone (Bobyn et al. 1999a). The elastic modulus is about 2.5-4.0 GPa, similar to subchondral bone. For comparison titanium has an elastic modulus of 110 GPa. The compressive strength of porous tantalum is 50 – 80 MPa. The compressive strength of other porous materials ranges from 3 – 150 MPa, for example trabecular bone (10 –50 MPa), cortical bone (130 – 150 MPa), and other porous metals (20-150 MPa). Bobyn et al. (1999a) inserted cylindrical implants of trabecular metal into the femoral diaphysis of mature mongrel dogs. They noticed by histological examination that the pores of the implants were filled with new bone (to
40% to 50%) in four weeks. By 16 to 52 weeks, they noticed bone ingrowth from 63% to 80%. Pull out tests of the implants revealed that half of the implants at 4 weeks and all or the implants at 16 weeks showed compressive failure before rupture of the implant-bone interface indicating a very strong bond of the implant to bone.

Because of these interesting properties, trabecular metal has recently been introduced into orthopeadics in the form of acetabular and tibial implants intended for uncemented use. In these implants, the polyethylene is attached to the metal by a direct compression moulding process that infuses the polyethylene into the trabecular metal with an uniform penetration of approximately 1.5 mm.

In an animal study, Bobyn et al. (1999b) used porous tantalum acetabular monoblock cups in total hip arthroplasty in dogs. They found that all 22 acetabular implants had stable implant-bone interfaces with regions of bone ingrowth present in all histologic sections. The depth of bone ingrowth varied from 0.2 mm to 2 mm and the mean ingrowth for all sections were 16.8%. Hacking et al. (2000) inserted porous tantalum into the subcutaneous tissue in dogs and found an attachment strength that was three- to six-fold greater than a similar experiment with porous beads. Histogical analysis revealed complete tissue ingrowth through the implant with neovascularization within the porous tantalum material. The gap healing ability of trabecular metal was excellent in a study where implants of trabecular metal and solid titanium with a glass bead blasted surface were inserted into the femoral condyles of the canine knee (Rahbek et al. 2005). The implants were inserted either with exact surgical fit or with a peri-implant gap. Both implants with surgical fit and with peri-implant gap showed superior bone ongrowth in the trabecular metal group compared to
the solid blasted titanium group. In fact, the trabecular metal implants with peri-implant gap had significantly higher bone ongrowth than the solid blasted titanium implants with exact surgical fit. In an experimental model Zhang et al. (1999) found a very high friction coefficient of porous tantalum material in comparison to natural bone autografts or allografts, and to conventional orthopaedic coating materials. The advantage of initial stability of an implant in uncemented designs is important and a high friction coefficient would presumably enhance the possibility for bony ingrowth or ongrowth. Florio et al. (2004) compared the flexibility of porous tantalum monoblock tibia and a stemmed titanium modular tibia and found higher flexibility of the tantalum component. This property could theoretically decrease load transfer to the interface and thereby reduce stress shielding. Clinical reports of trabecular metal implants are sparse. Gruen et al. (2005) followed 414 cases of trabecular metal acetabular cups (mean 33 months). Postoperative radiographs revealed acetabular gaps in 19% of the hips. At the last follow-up 84% of these gaps were completely filled in. In a radiological follow-up (mean 7 years) of 86 hips Macheras et al. (2006) found that all postoperative gaps had disappeared after 24 months. No component migration was found using the EBRA digital measurement method. There are only few short-term reports in the literature regarding trabecular metal tibial implants. Bobyn et al. (2004) reported a 2-year follow-up of 72 uncemented TMT implants. At the last follow-up there were no new or progressive radiolucent lines and no revisions. When comparing a group TKAs using a TMT with a group of standard cemented TKAs Ghalayini and McLauchlan (2004) found no clinical differences at a follow-up of 13 months. Bal et al. (2006) followed 115 total knees with a TMT implant for a minimum of 12 months and found no complications at all. There is only one
randomized study using RSA reported (Dunbar et al. 2007). They found no difference in micromotion at 1 year between a group of TMT implants and a group of fixed bearing TKAs. The TMT implants had a greater initial migration, but seemed to stabilize at 6 months postoperatively.

The properties of trabecular metal are close to normal bone and animal studies have shown evidence of bony ingrowth. Theoretical considerations indicate that this concept would enhance the fixation of implants to bone and thus be well suited for total knee arthroplasty in younger patients. Clinical reports are, however, few and no histological examinations of implants from humans have been published. No long-term studies are reported and indeed no studies in younger patients.

Radiostereometric analysis (RSA)

All studies in this thesis are based on the RSA method. The system of RSA was introduced by Selvik (1989). It has been in use for more than 25 years. RSA is a high-resolution method with the largest accuracy to measure micromotion in vivo. The method can be performed with an in vivo accuracy of 50-250 µm and 0.1-0.6° (Kärrholm 1989). Implantation of tantalum markers into the bone and the implant is required. The markers constitute two rigid bodies and the three-dimensional co-ordinates of these are determined by repeated x-ray examinations using a calibration cage and two angled x-ray tubes. The relative motion of the implant in relation to the bone over time can then be computed. The applications are numerous in the orthopaedic field (Kärrholm 1989). The method has a possibility to predict future loosening of implants (Kärrholm et al. 1994, Ryd et al. 1995) and is
recommended to assess aseptic implant loosening (Nilsson and Kärrholm 1996).

**Surgical technique**

In order to avoid asymmetric loading leading to stress of the implant-bone interface with increased risk of loosening, it is crucial to obtain a stable knee with normal alignment when performing a total knee arthroplasty. Besides from meticulous surgery when making the bone cuts, this is achieved by careful and adequate soft tissue release (Freeman et al. 1978). Malalignment is a risk factor for component loosening and the surgeon should aim at an alignment close to neutral or in slight valgus (Ritter et al. 1994).

All knees in this thesis were operated according to modern standard procedures and performed by three very experienced knee arthroplasty surgeons.
The need of total knee arthroplasty in younger patients is increasing, but the results are inferior and thus it is desirable to search for improved modes of fixation of components. Coating uncemented implants with hydroxy-apatite seems to improve fixation. There are no studies using RSA of HA coated TKAs in younger patients. Enhancing the tibial base plate with screws theoretically strengthens the fixation, but detrimental side effects as osteolysis around the screws have been reported. Whether screw fixation of HA coated tibial components reveals improved fixation in younger patients has not been studied. The concept of mobile bearing TKA theoretically uncouples the forces at the implant-bone interface, which presumably would enhance the fixation of the implant to bone. One RSA study of mobile bearing TKA is published concerning an uncemented design. There is no RSA study of the tibial fixation of cemented mobile bearing TKAs in the literature. Trabecular metal tibial components have several theoretical advantages that would improve implant fixation and thus suit the younger patient. No study of trabecular metal tibia in younger patients have been published. The best method of fixating the femoral component in younger patients is yet to be established. Uncemented fixation has not been evaluated in younger patients using RSA.
AIMS OF THE STUDY

- to evaluate the magnitude and pattern of migration of a mobile bearing cemented total knee prosthesis and to compare with a fixed bearing TKA.

- to compare the migration pattern and magnitude of an uncemented hydroxy-apatite coated modern designed total knee prosthesis with or without tibial screw fixation and a cemented total knee prosthesis of the same design in patients younger than 65 years.

- to evaluate the migration pattern of uncemented trabecular metal tibial implants in patients younger than 60 years.

- to compare the quality of fixation of cemented versus uncemented fixation of the femoral component in patients younger than 60 years.
MATERIAL

Patients

The entire material consists of 196 knees in 173 patients operated on between April 1997 and February 2005. The diagnosis were primary osteoarthritis (study II), primary or secondary osteoarthritis (studies I, III and IV) or rheumatoid arthritis (study I). Forty-one patients (47 knees) participated in both studies III and IV. The patients were consecutively selected from the waiting list at the department of Orthopaedics, Umeå University Hospital (study I), and the department of Orthopaedics, Falu General Hospital (studies II, III and IV).

Exclusion criteria were previous infection, malignant disease, severe osteoporosis and in study II also previous ipsilateral surgery. All studies in this Thesis were approved by the Ethics Committees of Uppsala University (studies II, III, IV) and of Umeå University (study I). Patients fulfilling the inclusion criteria entered the studies after having been informed verbally and in writing and had given their written consent. All eligible patients agreed to participate.

Patients with incomplete follow-up

Ten patients in study I were not available during their summer vacations and could thus not be followed up clinically or with RSA at 6 weeks. One patient in study I (in the no screws group), could not be analysed by RSA at all due to too few visible markers.

In study II, one patient in the MBK group died in myocardial infarction 2 weeks postoperatively and thus could not be followed up. Another patient
also in the MBK group, refused to attend the 2-year follow-up because of poor general health and thus have no RSA and clinical data at 24 months. In study III, the postoperative RSA in one patient in the TM CR group examination failed and hence no further analysis was possible. One patient in the NG CR group could not participate in the clinical follow-up at 24 months due to Alzheimer’s disease. One patient in the TM CR group was revised after 19 months.

In study IV, the postoperative RSA examination in one patient in the uncemented group failed and no further analysis was possible and another patient in the same group could not participate in the clinical follow-up at 24 months due to Alzheimer’s disease. A third patient also in the uncemented group, was revised at 19 months.

Patients with imperfections in the RSA examinations are listed in table 1.

Table 1. KNEES with incomplete follow-up due to RSA imperfections.

<table>
<thead>
<tr>
<th>Study</th>
<th>Poor RSA radiographs or too few markers visible</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 months</td>
</tr>
<tr>
<td>Study I cemented</td>
<td>1</td>
</tr>
<tr>
<td>Study I HA coated, no screws</td>
<td>3</td>
</tr>
<tr>
<td>Study I HA coated, screws</td>
<td></td>
</tr>
<tr>
<td>Study II, fixed bearing</td>
<td></td>
</tr>
<tr>
<td>Study II, mobile bearing</td>
<td>2</td>
</tr>
<tr>
<td>Study III, cemented</td>
<td></td>
</tr>
<tr>
<td>Study III, trabecular metal</td>
<td></td>
</tr>
<tr>
<td>Study IV, cemented</td>
<td>4</td>
</tr>
<tr>
<td>Study IV, uncemented</td>
<td>2</td>
</tr>
</tbody>
</table>

At 6 weeks there were no RSA imperfections.
Implants

The **NexGen Option CR (NG CR)** prosthesis (Zimmer, Warsaw, IN, USA) (Figure 1) was used in **studies II, III and IV**. It is a moderately conforming cruciate retaining, fixed bearing, and modular prosthesis for cemented fixation. The femoral component is made of a Cobalt-Chromium-Molybdenum alloy and the tibial base plate is made of Tivanium (Ti-6Al-4V) alloy. The femoral component has an asymmetric configuration with a larger radius laterally than medially (1.07-1.0) in order to facilitate normal femoral rollback during flexion. The tibial component has a 50-mm long central stem with small flanges projecting postero-laterally. The polyethylene (resin GUR 1050) insert is compression moulded and precision machined. It is gamma sterilized in nitrogen gas. The insert is kept fixed to the tibial base plate with a peripheral capture mechanism.

The porous coated femoral component (**study IV**) (figure 2) for uncemented use is covered with a titanium fiber mesh undersurface.

The **MBK** prosthesis (Zimmer, Warsaw, IN, USA) (Figure 3) is a mobile bearing cemented prosthesis used in **study II**. The tibial and femoral components are made of a Cobalt-Chromium alloy and the upper surface of the tibial implant is highly polished. The femoral component has a single radius matching the highly conforming articular surface of the polyethylene insert. Full contact occurs from 0° to 105° of flexion. The tibial base plate has a 50-mm central stem with small flanges projecting postero-laterally. The upper surface has a mushroom-shaped metal peg matching the mobile polyethylene bearing, which is connected to the tibial base plate with a snap-
Figure 1. The tibial component of the NexGen Option CR prosthesis. The left picture shows the tantalum markers encased in titanium rods.

Figure 2. The porous femoral component of the NexGen Option CR prosthesis with tantalum markers encased in titanium rods.

Figure 3. The MBK prosthesis
fit mechanism. The polyethylene component is from the same resin (GUR 1050) and is processed in the same way as the NexGen Option CR polyethylene. The mobile bearing has a build-up in the center to prevent medial-lateral translation of the femoral component. The mobile bearing permits 25° of inward and 25° of outward rotation, and 4.5 mm AP translation.

The Trabecular Metal CR (TM CR) (Zimmer, Warsaw, IN, USA) (Figure 4) prosthesis was used in study III. The Trabecular Metal Tibia (TMT) is a monoblock implant with a base plate of trabecular metal. The base plate has two hex-shaped pegs that can be press-fit into the tibial surface. The polyethylene (GUR 1020) is compressed into the trabecular metal by a direct compression moulding process. It is gamma sterilized in nitrogen gas. The tibio-femoral conformity is almost identical with the NexGen Option CR prosthesis.

![Figure 4. The trabecular metal tibia.](image)

The Profix (Smith & Nephew, Memphis, TN, USA) prosthesis is a modular, moderately conforming cruciate retaining prosthesis and was used in study I. The tibial trays are made of a 3-mm titanium alloy. The trays intended for cemented use (Figure 5) has a grit-blasted undersurface with a keel shaped stem. Trays for uncemented use (Figure 6) are porous coated with hydroxyapatite coating sprayed on. They have a short grit-blasted central stem and
Figure 5. The Profix prosthesis for cemented use. The grit-blasted undersurface to the right.

Figure 6. The Profix prosthesis for uncemented use without screws. The HA-coated undersurface to the right.

Figure 7. The Profix prosthesis for uncemented use with screws. The HA-coated undersurface to the right.
five tiny spikes. The trays intended for the use of screws (Figure 7) have four screw holes, whereas the trays used without screws have no screw holes. The polyethylene is made from GUR 1050 resin and sterilized with ethylene-oxide.

**Patellar components.** In study I the patellar component was of the inset type and made of all-polyethylene. The patellar component was used when the patients had substantial osteoarthritis and a native patella with concave articular surface. Five knees in the cemented group, eleven in the uncemented group with no screws, and nine in the uncemented group with screws had their patellae replaced.

In studies II, III, and IV the patellar components were of the onset type and all-polyethylene and identical in shape for the NexGen Option CR, the MBK, and the TM CR prostheses. The patella was resurfaced when the patient had patellar symptoms and a concave articular surface of the patella. In study II did five patients in the NexGen Option CR group and two patients in the MBK group receive a patellar component. In study III, the patella was resurfaced in three patients in each group. In study IV two patients in the cemented group and four in the uncemented group were resurfaced with a patellar component.
METHODS

Clinical evaluation

All patients were followed for 24 months with preoperative and postoperative knee scores. The Hospital for Special Surgery Score (study I) has been widely used (Insall et al. 1976b). This score incorporates a functional component and will therefore deteriorate as the patients get older. The Knee Society clinical rating system (Insall et al. 1989) (studies I, II, III, IV) is divided into a knee score that scores only the knee joint and a functional score that rates the ability to walk and climb stairs. The Knee Society Knee Score assesses pain, range of motion and stability of the knee to a maximum of 100 points. Subtraction of points are made for flexion contractures and radiographic malalignment. The Knee Society Function Score is also maximized to 100 points with subtraction when the patient uses walking aid. The Knee Society Function Score estimates the function of the patient as a whole, and in patients operated in both knees it is impractical to use if one is interested in the performance of both knees independently. Since many patients in studies III and IV were operated bilaterally, we used the Knee Society Knee Score and the Knee Society Pain Score for their evaluation, but not the function score.

Conventional radiography

The alignment of the knee in the frontal plane was measured as the Hip-Knee-Ankle (HKA) angle (Moreland et al. 1987). A line between the center of the femoral head and the midpoint of the tibial plateau forms an angle
with a line from the midpoint of the tibial plateau and the midpoint of the
talar plateau. The normal value of this angle is set to $180^\circ$. If this angle is less
than $180^\circ$, the knee is in varus malalignment, and if the angle is more than
$180^\circ$, the knee is in valgus malalignment. The examinations of the HKA
angle were made preoperatively and at 3 months postoperatively.
The alignment of the tibial component in relation to the long axis of the tibia
was measured postoperatively in the frontal and sagittal planes as described
The presence of radiolucent lines at the component interface were
determined on radiographs obtained with the beam tangential to the tibial
component according to the Knee Society (Ewald 1989). The size and
location of the radiolucent lines were documented and possible progression
of lines were analysed.

Randomization

The randomization process in studies I, II and IV was carried out by
opening of a sealed envelope during the operation. In study I the
randomization was between a cemented Profix prosthesis, an uncemented
Profix prosthesis without screws, and an uncemented Profix prosthesis with
screws. In study II the randomization was done between a standard NexGen
Option CR prosthesis and a MBK prosthesis. The randomization in study
IV was between uncemented femur and cemented femur. In study III the
intention was to randomize to surgeon in order to avoid any effects of
learning curve or surgeon’s bias. One surgeon (AH) with experience of
uncemented TKAs was planned to do the uncemented cases and another
surgeon, familiar with cemented TKAs should do the cemented cases.
However, the surgeon for the cemented cases had problems in recruiting
patients and therefore all patients were operated by the author in a consecutive series in order to finish the study in a reasonable time.

**RSA (Radiostereometric analysis)**

During the operations, 7-9 tantalum spheres (diameter 1.0 mm) were implanted into the bone as radiographic markers. Care was taken to scatter the markers widely in the bone. The implants (studies II, III and IV) were equipped with tantalum markers (diameter 1.0 mm) encased in titanium rods that were press-fit into the implant. The tibial plates in studies II and III had 4 markers on the undersurface of the tray and one at the tip of the stem. The femoral implants in study IV had 4 markers at the anterior and posterior parts of the implant, respectively, and one marker on each peg. Six tantalum markers (0.8 mm or 1.0 mm) were inserted into the polyethylene component in studies I and III.

The patients were examined supine with the knee of interest positioned inside a biplanar calibration cage (Cage 10, RSA Biomedical, Umeå, Sweden). The anatomic axes of the knee were parallel to the cardinal axes of the calibration cage at the initial reference examination. Two X-ray tubes were positioned with an angle of 90° between each other and used for simultaneous exposure. The initial RSA examinations were performed a mean of 3 (±1.4) days postoperatively in studies I and II, and a mean of 4 (±1.6) days postoperatively in studies III and IV. Subsequent examinations were done at 6 weeks, 3, 12 and 24 months in study I, at 3, 12 and 24 months in study II, and at 6 weeks, 3, 12, and 24 months in studies III and IV.

The RSA examinations were analysed using the UmRSA software (RSA Biomedical, Umeå, Sweden). The two-dimensional position of the markers
were determined with the UmRSA Digital Measure and then reconstructed into 3D-positions and 3D-motions with the UmRSA Analysis software. In order to obtain similar positions on the tibial implants for translation measurements in every implant, six standardized positions were reconstructed on the tibial tray (Nilsson et al. 1991). Five of these positions were located at the edge of the tibial tray medially, laterally, anteriorly, posteromedially and posterolaterally, and one at the center of the tray. These positions were plotted on the postoperative stereoradiographs and measured, and their relation to the real markers in the polyethylene (study I, III [the TMT implants]) or on the tibial tray (studies II, III) was calculated. Their positions on subsequent examinations were then transferred using the Point Transfer program in the RSA software using the implant markers as a reference. The radiographs were mostly analogue in studies I and II and were scanned using a UMAX PowerLook 2100 XL scanner (UMAX Technologies, Dallas, TX, USA) with 300 dpi spatial resolution. During the later parts of studies I and II and in all patients of studies III and IV the radiostereometric radiographs were digital with 223 dpi spatial resolution. The markers in the proximal tibia (studies I, II and III) and in the distal femur (study IV) were used as a fixed reference segment. The relative movements of the segment made up of the tantalum markers in the tibial base plates and the femoral component, respectively, were calculated in relation to the reference segments.

The quality of the RSA examinations is determined by the number of markers, the condition number, and the mean error of rigid body fitting (Valstar et al. 2005). The condition number is a measure of the quality of dispersion of the markers in each segment and should be lower than 100. Mean error of rigid body fitting is a measure of marker stability and should
not exceed 0.30. The values of the condition number and the mean error of rigid body fitting are listed in table 2.

Table 2. Condition number and mean error of rigid body fitting

<table>
<thead>
<tr>
<th>Study</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition number</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tibia or femur</td>
<td>27</td>
<td>29</td>
<td>33</td>
<td>63</td>
</tr>
<tr>
<td>Implant</td>
<td>21</td>
<td>20</td>
<td>24</td>
<td>37</td>
</tr>
<tr>
<td><strong>Mean error of rigid body fitting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tibia or femur</td>
<td>0.19</td>
<td>0.22</td>
<td>0.16</td>
<td>0.23</td>
</tr>
<tr>
<td>Implant</td>
<td>0.13</td>
<td>0.13</td>
<td>0.09</td>
<td>0.09</td>
</tr>
</tbody>
</table>

The migrations of the implants were expressed as rotations around the cardinal axes. Transverse rotation (X-axis) is anterior (+) – posterior (-), longitudinal rotation (Y-axis) is internal (+) – external (-), and sagittal (Z-axis) is varus (+) – valgus (-). Lift-off and subsidence represent proximal and distal translations of the tibial component, respectively (studies I, II, and III), while in study IV subsidence was defined as any type of movement resulting in prosthetic motion into the bone and lift-off as translation away from the bone.

The largest value of a standardized point for subsidence and lift-off was chosen as maximum subsidence and maximum lift-off. MTPM (Maximal Total Point Migration) is the vectorial length of the three-dimensional translations of the point that moved the most (Ryd 1986). Movements of the PE liner in relation to the metal baseplate can occur also in fixed bearing modular components (Nilsson et al. 2003, Hansson et al. 2005). These movements occur most entirely as rotations in the horizontal plane (ie, internal-external rotation) equivalent to anterior-posterior (AP) and medial-
lateral translation. When using modular components with markers only in the PE (study I), it is impossible to determine how much of such recorded movements are occurring between the PE and the baseplate, and between the baseplate and the bone, respectively. Therefore, MTPM was not used in study I. In studies II, III and IV, however, the MTPM measurement were based on the markers inserted on the tibial tray, the femoral component, or in the polyethylene of the monoblock trabecular metal tibia, and could therefore be relied on. MTPM has been used for prediction of future risk for loosening by Ryd et al. (1995). The change of MTPM between 12 and 24 months should not exceed 0.2 mm for a component to be classified as stable, otherwise it is classified as continuously migrating.

The precision of the RSA measurements was determined with double examinations of all patients at each follow-up interval according to Ranstam et al. (2000). Significant values at a 95% level of significance are illustrated in table 3.

<table>
<thead>
<tr>
<th>Study</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse axis</td>
<td>0.18</td>
<td>0.17</td>
<td>0.25</td>
<td>0.37</td>
</tr>
<tr>
<td>Longitudinal axis</td>
<td>0.20</td>
<td>0.21</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>Sagittal axis</td>
<td>0.18</td>
<td>0.19</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>Subsidence and lift-off (mm)</td>
<td>0.10</td>
<td>0.10</td>
<td>0.11</td>
<td>0.15</td>
</tr>
</tbody>
</table>

### Histology

One trabecular metal tibial component was retrieved at revision (paper III). The tibial tray was cut through the pegs with a few mm of proximal tibial bone and the pegs then were trephined out with 1-2 mm surrounding bone
tissue. The implant-bone specimens were fixed *en bloc* in formaldehyde, processed, and embedded in methyImethacrylate undecalcified. On an EXAKT® saw-cutting machine 4 serial coronal sections were made through the tibial implant at about 100 microns. The pegs were treated identically and grounded to a thickness of less than 50 microns. Surface staining with blue-basic fuchsins was used.

**Statistics**

The statistical methods used are described and accounted for in the respective papers.
RESULTS

Summary of papers I – IV

Paper I

*Uncemented HA-coated Implant is the Optimum Fixation for TKA in the Young Patient.*

Patients and preoperative data

Eighty-five patients (97 knees) with osteoarthritis or inflammatory arthritis were operated with TKA. They were randomized into three groups having different types of fixation of the tibial component. Cemented, uncemented (HA coated) with screws, or uncemented (HA coated) without screws. Preoperative demographic or clinical data did not differ between the groups with one exception; the uncemented groups had larger preoperative varus malalignment (Kruskal-Wallis test, $p < 0.05$). The patients were followed for two years with clinical scores (Knee Society Knee Scoring System and Hospital for Special Surgery Score) and RSA examinations.

RSA results

At 3 months postoperatively, the migration of the cemented implants was less than the migration of the uncemented implants (Kruskal-Wallis test). Post hoc analysis with Mann Whitney U test revealed no differences between the two uncemented groups. At 24 months, there were no differences in the magnitude of migration either in AP rotation, varus-valgus rotation, maximal
subidence or maximal lift-off between the groups. The pattern of migration differed between the cemented implants and the uncemented implants. The cemented implants migrated continuously until the 2-year followup. The uncemented groups, on the other hand, had all their migration during the initial 3 months and stabilized thereafter. There were no statistically differences in pattern or magnitude of migration between the two uncemented groups. Maximum lift-off increased in all three groups up to the 2-year examination.

Clinical and radiographic results
The clinical results improved during the follow-up with no differences between the groups (Kruskal-Wallis test). Radiolucent lines were not seen in any implant postoperatively. In the cemented group about 25% of the implants developed thin (≤ 1 mm) radiolucent lines at the most medial or lateral centimeter of the tibial tray. In no case were these lines progressive. In the uncemented groups were no radiolucent lines seen with one exception. This knee (HA coated, no screws) displayed a large tilting of the implant up to 6 weeks and developed a radiolucent line with 1 to 2 mm thickness. However, after 6 weeks this implant stabilized up to 2 years and the radiolucent line disappeared gradually. No osteolytic lesions around the screws or under the trays were seen in any knee of the three groups.

Conclusion
The cemented implants displayed less migration the initial three months than the uncemented implants, but at 2 years there were no difference. The cemented implants migrated continuously during the entire follow-up period. The uncemented groups displayed all their migration the first 3 months, except of implant lift-off, which was continuously increasing up to 2 years.
There were no differences in magnitude or pattern of migration between the two uncemented groups indicating that screws do not improve fixation. Uncemented fixation with hydroxyapatite coated implants without screws seems to be a good solution for young patients, though the finding of implant lift-off is concerning.

**Paper II**

*Mobile Bearings Do Not Improve Fixation in Cemented Total Knee Arthroplasty.*

**Patients and preoperative data**

Forty-seven patients (52 knees) with primary osteoarthritis were randomized to receive either or NexGen Option CR fixed bearing total knee arthroplasty or a MBK mobile bearing total knee arthroplasty. The patients were followed with RSA examinations and clinically using the Knee Society Scoring System for two years.

**RSA results**

The magnitude of migration did not differ between the implants during the follow-up. The mean and median values were small with a few outliers in both groups. The direction of the rotations was evenly distributed between rotations around the X-axis, Y-axis, and Z-axis. The pattern of migration differed between the groups in vertical translation of the tibial tray. These tilting movements implied a median lift-off of the medial and central parts of the NexGen implants, whereas the MBK implant displayed subsidence into
The maximum subsidence from 3-24 months was significantly larger for the MBK implant (p=0.05, repeated measures ANOVA), and maximum lift-off was significantly larger for the NexGen implants (p=0.02, repeated measures ANOVA). The number of unstable implants according to Ryd et al. (1995) were 6 in the MBK group and 3 in the NexGen group (ns).

**Clinical and radiographic results**

The Knee Society scores increased during followup. There were no differences in clinical results between the groups (Mann-Whitney U test). In seven knees in each group thin radiolucent lines developed under the most medial, lateral and posterior part of the implant. In no case was there progression in thickness of the radiolucent lines and no lines were seen at or around the entire stems. The magnitude of migration was not greater in implants with thin radiolucent lines compared with the ones without such lines. The tibial component alignment did not differ between the groups in either the frontal or the sagittal plane.

**Conclusion**

The hypothesis that mobile bearing implants would result in improved fixation of the tibial component could not be confirmed. The mobile bearing implants did not perform better than the fixed bearing implants in any aspect. It might be that the somewhat stiffer Co-Cr baseplate used in the MBK knees and the different design of the articular surface in some unknown way counteracts any potential positive effect of the mobile bearing.
Paper III

*Trabecular metal tibial component in total knee arthroplasty in patients younger than 60 years. A prospective RSA study.*

Patients and preoperative data

Forty-one patients (47 knees) aged 60 years or younger with osteoarthritis were operated with either a cemented NexGen Option CR modular TKA or an uncemented monoblock trabecular metal tibia (TM CR). Due to imperfections of the randomization process, the operations were performed consecutively by the same surgeon (AH). The patients were followed by RSA examinations and radiological evaluation for 2 years. Clinical follow-up were done according to the Knee Society Scoring System.

RSA results

The TM CR implants displayed larger magnitudes of migration in AP rotation, varus-valgus rotation and internal-external rotation than the cemented implants at 3 and 24 months (Mann Whitney U test). The TM CR implants also subsided more than the cemented implants, but there were no differences of implant lift-off. However, the values for maximal lift-off in the TM CR group were below the precision of the RSA method, whereas the values in the cemented group were equal to or larger than the precision. In about 25% of the TM implants there were subsidence of one part of the implant and lift-off of the contralateral part. Two implant in the TM CR group and three in the cemented group were defined as unstable according to Ryd et.al (1995). This difference was not statistically significant. Both groups migrated up to 3 months and then they stabilized with one exception; the
stabilization in internal-external rotation for the TM CR implants occurred first after 12 months.

Clinical and radiological results

The Knee Society knee score and pain score improved during follow-up. The NG group displayed higher knee score at 12 and 24 months due to better range of motion, but the pain score did not differ between the groups. The HKA angle and the alignment of the tibial component in relation to tibia was the same in both groups postoperatively. Radiolucent thin lines were seen in about 50% of the NG group and in one implant of the TM group at 24 months. None of these lines were progressive.

Conclusion

Both groups migrated up to 3 months and then stabilized, with the exception of external rotation of the TM implants, which stabilized first at 12 months. The majority of the TM implants displayed subsidence with no lift-off. This pattern with no lift-off is regarded beneficial for uncemented fixation and thus may be suited for younger patients.
Paper IV

_Cemented versus uncemented fixation of the femoral component of the NexGen CR total knee replacement patients younger than 60 years. A randomized RSA study._

Patients and preoperative data

41 consecutive patients (47 knees) were randomized to received either a cemented NexGen femoral component or a porous-coated uncemented NexGen femoral component. The patients were 60 years or younger with primary or secondary osteoarthritis. Preoperatively there were no differences in age, Knee Society Score or knee alignment between the groups. Follow-up with RSA, radiological and clinical evaluation was done up to 24 months postoperatively.

RSA results

There were no differences in rotation around the three cardinal axes at 3, 12 or 24 months (Mann Whitney U test). Most of the rotation occurred up to three months. Maximum subsidence and maximum lift-off did not differ between the groups and in both groups took place mainly during the first three months. No significant difference regarding MTPM was found and four implants in each group were defined as continuously migrating.

Clinical and radiographic results

The clinical results measured as the Knee Society knee score and pain score improved over time. At 24 months, there were no differences between the
groups. The HKA angle did not differ between the groups. Two thirds of the cemented implants and half of the uncemented implants developed thin radiolucent lines during follow-up. In no case were these lines progressive.

**Conclusion**

Since no differences between cemented and uncemented porous coated femoral component of the same design could be detected either in magnitude or pattern of migration or in clinical scores, it seems that uncemented fixation of the femoral component is equally as good as cemented fixation in the young patient. Uncemented fixation could be an advantage in infection of a TKA.
DISCUSSION

The results of total knee arthroplasty in younger patients are inferior (Robertsson et al. 2001, Gill and Joshi 2001, Furnes et al. 2002, Harrysson et al. 2004, Gioe et al. 2007) and the demand for total knee arthroplasty in this group of patients is increasing (Robertsson et al. 2000, Laskin 2002, Ritter 2002). Loosening of components, especially on the tibial side is, besides polyethylene wear, the major cause of failure both in older (Moreland 1988, Knutson et al. 1994, Sharkey et al. 2002) and younger patients (Robertsson et al. 2001, Harrysson et al. 2004). Younger patients have a higher level of activity and a longer life expectancy that will put higher stresses and demands on the implants. Total knee arthroplasty in the younger age group should therefore have designs and modes of fixation that will last 25 years or longer.

Mobile bearing total knee arthroplasty was introduced as a mean to reduce polyethylene wear and improve the kinematics and the fixation of the implant to bone (Goodfellow and O’Connor 1986, Buechel and Pappas 1986). Theoretically, this design would uncouple the forces acting on the interface and hence lower the risk of tibial component loosening. The kinematics of the artificial knee improves in mobile bearing TKAs compared to fixed bearing TKAs (D’Lima 2000, Dennis and Komistek 2006) and the stresses at the implant-bone interface is reduced experimentally (Bottlang et al. 2006). The contact stress is reduced ((Matsuda et al. 1998, Stukenberg-Colsman et al. 2002, Sharma et al. 2007) and the polyethylene wear is less than that of fixed bearing TKAs (Tsakonas and Polyzoides 1997).

No superiority of mobile bearing TKAs compared to fixed bearing TKAs have been shown though good long-term results have been reported (Buechel 2004, Callaghan et al. 2005, Tarkin et al. 2005). One study in younger patients showed excellent result after 7 years (Morgan et al. 2007).
There are only two randomized studies in the literature concerning mobile bearing TKA. Aglietti et al. (2005) found no clinical differences between fixed or mobile bearing TKA in a short-term study. Using uncemented fixed and mobile bearing TKAs Hansson et al. (2005) in a RSA study found no differences in clinical results or migration between the two concepts.

In study II we used RSA to evaluate the migration of the NexGen Option CR fixed bearing and the MBK mobile bearing arthroplasties with cemented fixation. The patients in this study had a mean age of 72 years (62-84 years). Since the potential benefits of mobile bearing TKA may be larger in younger patients, ideally such patients should have been examined. However, the incidence of osteoarthrosis treated with TKA is still, though slowly increasing, low in Sweden and in order to recruit patients in a reasonable time for the study to finish, we choose not to use younger patients. Since our interest was to study the pattern of migration, any differences between the two designs, using a high-resolution method such as RSA, would have been identified even in older patients.

The magnitude of migration was similar in both groups. The number of unstable implants according to Ryd et al. (1995) was twice as many in MBK group (6/23) compared to the NG CR (3/26). This difference is, however, not statistically significant. Hansson et al. (2005) found the same tendency with 4 out of 19 unstable implants in the mobile bearing group compared to one out of 18 in the fixed bearing group. This difference was not significant either. Interestingly, the magnitude of internal-external rotation in our study did not differ between the groups. A freely rotating PE-liner would theoretically transmit less force to the implant-bone interface and thus induce less rotation of the tibial implant in relation to bone. The ability of a mobile PE-insert to rotate has been shown by Fantozzi et al. (2002) and Komistek et al. (2004). The magnitude of rotational migration of the tibial tray in the
MBK knees in our study might suggest that the PE-liners did not have the capacity to rotate on the tibial tray or that the forces between the liner and the tray during weight-bearing prevented rotation and thus increased the forces at the implant-bone interface, as proposed by Otto et al. (2001). The pattern of migration in vertical translation differed between the fixed and the mobile bearing groups. Both types of implants showed tilting movements with subsidence of some part of the tray and lift-off of the other. The MBK tibial trays subsided more, whereas the NG CR trays displayed more lift-off. There is no obvious reason for this finding. It might be that the stiffer Co-Cr tibial tray or the higher conformity of the mobile bearing prosthesis counteracts the potential effects of the mobile bearing.

Cemented joint arthroplasties have some potential disadvantages. Sign of osteolytic activity have been found at the cement-bone interface even in clinically stable implants (Linder and Carlsson 1986, Fornasier et al. 1991, Schmalzreid et al. 1992, Bos et al. 1995). Macrophages and wear particles of cement and PE are found at the interface. Activation of macrophages from wear particles can induce bone resorption (Schmalzreid et al. 1992, Bos et al. 1995). Numerous RSA studies have revealed a typical pattern of migration of cemented TKAs (Nilsson et al. 1991, Nilsson and Kärrholm 1993, Önsten et al. 1998, Nilsson et al. 1999, Carlsson et al. 2005). The initial migration is small, mainly because the cement act as a filler that can accommodate for the imperfections of the exposed tibial surface. The cemented implants then continue to migrate over time, a process that does not stop after 2 years but continues further on (Nilsson et al. 1999, Carlsson et al. 2005), even up until 10 years (Nilsson and Dalén 2008). This pattern of migration could be interpreted as a sign of continuous bone resorption at the interface (Linder 1994), a process that may not be of any importance in the group of older
patients receiving knee replacements, but might interfere with long-term fixation in younger patients.

The cemented tibial implants in younger patients in study I displayed this typical pattern of migration and, though not stated in paper II, so did the NG implants in study II. In contrast to these and earlier findings of cemented tibial components, the NG implants in study III displayed a different pattern of migration. The NG implants migrated initially, but stabilized after 6 weeks. Furthermore, the magnitude of migration was smaller than previously found for cemented tibial implants. There is no obvious explanation for this pattern. Bertin et al. (2002) showed that the kinematics of the NG CR prosthesis were more close to the kinematics of the normal knee than other TKAs studied, and maybe this could lead to less stresses of the interface. The NG CR prosthesis has a peripheral lip at the undersurface, that, as suggested by Vertullo and Davey (2001), increases the cement penetration on impaction. Clinical reports of cemented NG CR are in favour with this pattern of migration. Bertin (2007) found no prosthetic failure of the NG CR arthroplasty in a mid-term follow-up and this design is also the best performing prosthesis in SKAR (Lidgren et al. 2007). It might be that the NexGen CR prosthesis have a more favourable design than other cruciate retaining TKAs. Nevertheless, the NG implants in study II displayed the typical pattern of continuous migration of cemented implants. Maybe the stronger bone in the younger patients in study III could withstand the forces acting on the implant-bone interface better and thus reduce the magnitude of migration to values below the precision of the RSA method. Longer follow-up of these implants will be needed to evaluate this. A constant finding in both the cemented Profix prosthesis in study I, the MBK and the NG CR prostheses in study II and the NG CR prosthesis in study III is implant lift-off. This is a concern since lift-off has a potential of
exposing the interface and thus a possibility of entrance of joint fluid
containing wear particles, which, if activating macrophages could lead to
bone resorption and in the end a higher risk for implant loosening. Lift-off is
a common finding in metal-backed tibial components (Nilsson and Kärrholm
1991, Nilsson et al. 1999). The stiffness of the metal tray might be an
explanation for this behaviour.
Coating uncemented implants with hydroxyapatite (HA) has proven to
enhance the fixation to bone (Bellemans 1999, Søballe et al. 1999). Several
RSA studies of HA-coated tibial components have shown improved fixation
compared to cemented or uncemented components without HA coating
(Nelissen et al. 1998, Nilsson et al. 1999, Toksvig-Larsen et al. 2000, Regnér
baseplates with screws was shown to enhance the initial stability of the
implants (Voltz et al. 1988, Lee et al. 1991). Osteolytic lesions were, however,
seen frequently (Peters et al. 1992, Lewis et al. 1995, Berger et al. 2001b,
Goldberg and Kraay 2004). To my knowledge there are no randomized
studies of HA-coated tibial components in younger patients and no studies
of screw-inforced tibial components in younger patients either.
In study I we choose to recruite patients younger than 65 years old in order
to finish the study in a reasonable time. However, only 18 of 97 knees (18
%) were in patients older than 60 years, equally distributed in the different
groups. The tantalum markers were spread into the PE liner. Movements of
the PE liner in relation to the tibial base plate can occur (Nilsson et al. 2003,
Hansson et al. 2005). These movements occur most entirely as rotations in
the horizontal plane equivalent to AP and medial-lateral translation. To
determine if some amount of the recorded movements are between the PE
liner and the base plate or between the base plate and the bone, respectively,
is impossible if there are not markers in the tibial tray as well (which was not
the case in study I). Therefore the rotations of the tibial component were only measured around the transverse and sagittal axis, and the translations only along the vertical axis (subsidence and lift-off).

The uncemented implants displayed most of their migration the first 3 months and then stabilized, in contrast to the cemented implants that migrated continuously. The initial migration of the HA-coated groups was greater than that of the cemented implants. This is explained by the imperfections of the cut surface of the proximal tibia. After cutting, the surface has irregularities with 1.0 to 2.4 mm difference between the highest and lowest points (Toksvig-Larsen et al. 1991). The uncemented implant, therefore, subsides until it settles on sufficiently wide and strong bone that resists the forces acting on it. The migration stops when the implant has settled, indicating a biologically mature interface. Since HA is osteoconductive, a prerequisite for bony ingrowth or ongrowth are present. Moreover, HA has a potential to seal gaps between implants and bone (Rahbek et al. 2000). In the patient in whom the implant tilted during the first week and also developed a radiolucent line under the entire lateral part of the implant, the implant stabilized at 6 weeks and the radiolucent line disappeared gradually presumably as a result of the osteoconductive properties of HA. There was one exception from the stabilization of the HA-coated implants between 3 and 24 months, implant lift-off increased in the same way as the cemented groups up to 2 years. This is a concern, since lift-off might have the potential to expose the interface to joint fluid. However, it might be that the sealing property of HA (Søballe et al. 1999, Rahbek et al. 2000) is sufficient to counteract the effect of lift-off in HA-coated implants as compared to the cemented implants. Longer follow-up will be needed to evaluate this. There were no differences in the magnitude or the pattern of migration between the uncemented HA-coated groups with or without
screws indicating that screws do not improve fixation of tibial implants to bone.

Trabecular metal have several theoretical advantages with properties similar to bone (Bobyn et al. 1999a). A high friction coefficient (Zhang et al. 1999) may enhance initial stability and a low stiffness (Florio et al. 2004) may transfer less load to the interface, as shown by Adalberth et al. (2000) in all-polyethylene components. The trabecular metal tibial components in study III displayed a similar pattern of migration as other uncemented tibial components, i.e. a greater initial migration followed by stabilization. However, some exceptions from this pattern were seen. The tibial components stabilized at 3 months except in internal-external rotation that did not stabilize until 12 months. The reason for this might be that the design with only 2 pegs may not be enough to resist the externally rotating forces acting on the implant. Rotation about the transverse axis, which is in line with the 2 pegs, was also larger than about the sagittal axis. Three or four pegs would theoretically resist those rotational forces better.

Initial stability is crucial for bony ingrowth or ongrowth. Toksvig-Larsen et al. (1998) found inducible displacement of tibial components at 6 weeks postoperatively, but speculated that this may be due to elastic micromotion within the cancellous bone and thus not preclude bony ingrowth. According to Bellemans (1999) will fibrous integration of the tibial implant lead to increased migration not becoming apparent until after 1 year. The complete stabilization of the TM implants at 12 months in our study might, therefore, indicate a possibility for bony ingrowth or ongrowth. Another exception from the typical pattern of migration was that the majority of the trabecular tibial implants subsided with the entire implant into tibia. This is an important finding because of the absence of lift-off. The reason for this
behaviour might be the low stiffness of trabecular metal as suggested by Florio et al. (2004). The subsidence was 0.8 mm at 6 and 3 months and is presumably the reason for the disappearance of all but one of the nine thin radiolucent lines found postoperatively. Moreover, gap healing properties of trabecular metal have been shown by Bragdon et al. (2004) and Rahbek et al. (2005). Lift-off was seen in about 25% of the trabecular tibial implants, mostly occurring up to 6 weeks. Subsidence was less in these implants than in those that showed subsidence of the entire implant. Possible explanation for this may be that the tibial bone in these patients was stronger and tilting of the implant with small subsidence of one part resulted in lift-off of the opposite part despite the less stiff component. Longer follow-up will be needed to evaluate the outcome and the consequences of these lift-offs.

One retrieved component showed no bony attachment at the base plate at histological examination. Instead, it was covered by a dense layer of fibrous tissue growing into the porous coating. Hacking et al. (2000) demonstrated complete ingrowth of fibrous tissue with high attachment strength into porous tantalum. Close bone apposition was seen in the pegs with ingrowth to a depth of 1 to 2 pores. Animal studies (Bobyn et al. 1999a, Bobyn et al. 1999b) have shown sufficient bony ingrowth into trabecular metal, but no reports of ingrowth regarding implants in humans have been published. The distinction between ingrowth and ongrowth is unclear. In order to establish a sufficient interlocking between bone and implant one might expect at least formation of bone past a trabeculum of the porous coating. It is, however, not clear whether the knee with the retrieved component was infected or not. The presence of an infection would probably disturb any possible bony ingrowth. The dense, well-organized fibrous tissue would, however, unlikely be formed in face of an ongoing infection. Furthermore, it might be that
bony ingrowth in human tissue takes considerably longer time than in animals.

Aseptic loosening of the femoral component is a lesser problem than that of the tibial component (King and Scott 1985, Keating et al. 2002). Some authors, however, report substantial problems with a high revision rate (Mulhall et al. 2006) or a high frequency of osteolysis (Goldberg and Kraay 2004). Excellent results with no femoral loosenings in long-term studies of both cemented (Schai et al. 1998, Berger et al. 2001a) and uncemented (Schröder et al. 2001, Berger et al. 2001b, Whiteside 2001) TKAs have been reported.

The optimum mode of fixation of the femoral component is still not determined. Two RSA studies have evaluated the femoral fixation. Nilsson et al. (1995) found no difference in migration between uncemented and cemented implants. Using HA coating of the femoral component Uvehammer et al. (2007) could not find any difference either. In study IV a comparison between porous coated uncemented and cemented femoral components were made in younger patients. No difference either in magnitude or pattern of migration, in clinical or radiographic results were found. The uncemented components displayed the same pattern as the uncemented tibial implants in studies I and III with a large initial migration followed by stabilization at 3 months. However, the cemented femoral components displayed a similar pattern, in contrast to the cemented tibial implants in studies I and II, which showed the typical pattern of cemented tibial components with a small migration initially and a continuous migration over time. One reason for this difference between femur and tibia might be the anatomical differences, with femur having fixation surfaces in three directions.
In younger patients, it does not seem to matter which mode of fixation to choose. Tai and Cross (2006), in a long-term study of patients younger than 55 years, found no femoral loosenings of HA coated components. Uvehammer et al. (2007) could, however, not find that HA coated femoral components performed better than cemented femoral components. Apart from shortening the operation time, uncemented components can to a higher extent than cemented components be kept in situ in cases of deep infection according to Dixon et al. (2004). The reason for this may be the absence of a partial necrotic interface in contrast to cemented components.

The typical pattern of migration of cemented implants with continuous migration over time may not be of any clinical importance in elderly patients. In younger patients, however, with their higher level of activity and longer life expectancy, cemented implants may not be the best alternative. Coating uncemented tibial implants with hydroxy-apatite have been shown to enhance fixation to bone and the pattern of migration of those implants with early stabilization could indicate a better long-term prognosis of fixation in younger patients. Trabecular metal tibial implants subside into the tibia and stabilize completely at one year, a pattern that indicates a good long-term prognosis in younger patients. Since both hydroxy-apatite coating and trabecular metal seem to have osteoconductive properties it would be interesting to evaluate hydroxy-apatite coating of the trabecular metal implants. It does not seem to matter which mode of fixation of the femoral component to choose in younger patients.
CONCLUSIONS

- A hydroxy-apatite coated modern total knee prosthesis migrated more than a cemented total knee prosthesis of the same design initially, but stabilized at 3 months. Screw fixation of a hydroxy-apatite coated tibial implant displayed the same pattern and magnitude of migration as a hydroxy-apatite coated tibial implant without screws. This indicates a good long-term prognosis of fixation of hydroxy-apatite coated implants in younger patients and furthermore that screw fixation do not enhance fixation to bone.

- A mobile bearing cemented total knee prosthesis displayed the same magnitude and pattern of migration as a fixed bearing cemented total knee prosthesis. The theoretical advantages of fixation to bone of mobile bearing prostheses could not be confirmed.

- The majority of the trabecular tibial implants subsided into the tibia without any lift-off. Complete stabilization of the trabecular tibial implants occurred at 12 months. This indicates a good long-term prognosis of fixation of trabecular metal implants in younger patients.

- The quality of fixation of cemented or uncemented femoral components in younger patients did not differ. It is at the surgeon’s discretion to choose the mode of fixation of the femoral component in younger patients.
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