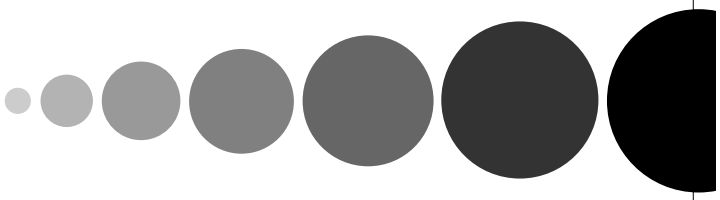
Objective clinical performance outcome of total knee prostheses. A study of mobile bearing knees using fluoroscopy, electromyography and roentgenstereophotogrammetry

Garling, E.H.

Chapter 9



Periapatite may not improve micromotion of knee prostheses in rheumatoid arthritis

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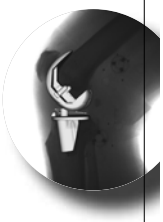
Abstract

Prosthesis migration in bone inevitably occurs in cemented and uncemented total knee arthroplasty tibial components. Cemented designs as the gold standard give immediate fixation whereas cementless designs need a period of bone ingrowth onto the surface irregularities of the implants. The addition of bioactive coatings may enhance this process of ingrowth.

A controlled randomized prospective RSA study was carried out on 26 Duracon implants in a rheumatoid arthritis patient group to evaluate the effect of a periapatite coating on the fixation of the tibial tray. The coated and the noncoated groups were matched for sex, age, body mass index, and HSS Knee Score. Stage of preoperative joint destruction and preoperative and postoperative mechanical leg axis showed no differences. We saw no differences in migration between the two groups, but a trend for lesser translations along and rotations about all three axes in the periapatite group. The periapatite-coated components showed a lower variance in subsidence than did the uncoated components. Both groups also showed a high variance in anterior tilting of the components.

The cementless PA-coated Duracon prosthesis used in patients with RA may provide improved fixation of tibial components although we could not demonstrate improvement in this small controlled series.



9.1 Introduction

Prosthetic joint replacement in patients with rheumatoid arthritis (RA) has a major impact on the quality of life of these patients (Nelissen, 2003). Problems that are specific to patients with RA as opposed to patients with osteoarthritis typically include younger age and more osteoporotic bone, both of which have a negative effect on prosthesis fixation. Although acrylic bone cement is the primary load-bearing material used for the attachment of orthopaedic devices to adjoining bone, degradation of acrylic-based cements in time results in a loss of structural integrity of the bone-cement-prosthesis interface and limits the longevity of cemented orthopaedic implants (Hoffmann et al., 1997; Sabokbar et al., 1997; Shardlow et al., 2003). Next to the cement deterioration itself, these small cement particles will also cause locally osteolysis with subsequent prosthesis loosening. In a rat model, titanium implants surrounded by bone showed less fibrous tissue interface after injection of PE particles than did partially ingrown implants. Within this fibrous tissue interface, foreign-body granulomas with macrophages differentiating into bone-resorbing cells are active (Brooks et al., 2000; Weir et al., 1996). Monocytes and macrophages are capable of differentiating into osteoclastic bone-resorbing cells in reaction to bone cement particles. Radio-opaque additives like barium sulphate ($BaSo_4$) and, to a lesser degree, zirconium dioxide (ZrO_2) or bone cement without radio-opaque additives are associated with bone resorption (Sabokbar et al., 1997; Wimhurst et al., 2001).

A potential advantage of cementless prostheses is that a good bone-prosthesis interlock will last longer, which will be especially of value in the younger population. However, these cementless knee prostheses account for only 2% of implants listed in the Swedish knee registry. In the Swedish registry, the most common diagnosis in patients younger than 55 years was RA (Robertsson et al., 2001). Enhancement of cementless prosthesis fixation is possible with hydroxyapatite (HA), which stabilizes initially unstable prostheses by osteoconduction through the calcium phosphate coating. Furthermore, HA is beneficial in gap healing of up to 2 mm and it converts fibrous tissue to bone around loaded implants (Søballe et al., 1993). The latter is advantageous in more osteoporotic bone that is commonly seen in patients with RA.

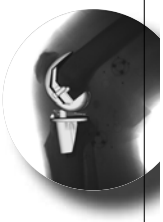
The importance of early prosthesis fixation is stressed by its relation to long-term survival of the prosthesis (Ryd et al., 1995). HA can increase the percentage ingrowth of bone into cementless implants. This bony interlock with the coating also seals off the prosthesis–bone interface, creating a barrier for PE wear particles, which are known to be another source of osteolysis and prosthetic loosening in the long term (Rahbek et al., 2001). The latter phenomenon will cause prosthesis migration and, in the longer term, prosthesis loosening. Thus, by enhancing the bone-prosthesis fixation with a calcium phosphate coating, less migration can be expected than without coating.

We hypothesized augmentation of a calcium phosphate coating to tibial components will provide a better fixation than noncoated component in a RA population.

9.2 Materials and methods

We prospectively enrolled 21 consecutive patients with RA undergoing primary cementless TKA (26 knees) and compared component migration RSA study. A power analysis based on data reported in a previous RSA study (Nelissen et al., 1998), suggested a significant difference in subsidence of 0.3 mm could be observed when 12 knees were included in each group. During surgery, patients were randomized to receive an uncoated Duracon (Stryker, Montreux, Switzerland) implant or a Duracon implant coated with PA. There were 11 patients (14 knees) in the PA group and 10 patients (12 knees) in the uncoated group. Descriptive statistics of the two groups (sex, age, body mass index [BMI], Hospital for Special Surgery [HSS] Knee Score and stage of radiographic arthritis [Insall et al., 1976]) showed no differences between the two groups supporting the homogeneity of the groups (Table 2). The preoperative and postoperative mechanical leg axes were similar in the two groups. One patient died unrelated to the knee prosthesis procedure, before the 1-year follow-up; no other patients were lost to follow-up.

The Duracon knee implant is a posterior cruciate ligament (PCL)-retaining nonconstrained knee replacement system. All tibial base plates had a cruciform keel



for rotational stability and the same porous-coated multiple-layer bead ingrowth surface. In general, HA coating is applied with a plasma-spraying process (Nelissen et al., 1998; Onsten et al., 1998), but this technique is not appropriate to coat the deeper layers of a porous-surfaced prosthesis. The Duracon porous-coated surface consists of multiple layer beads (diameter 0.4 mm) with a porosity of 35%, a mean pore size of 425 μm, and a thickness of 1.5 mm. During the PA coating technique, the prosthesis is submerged in a watery bath of calcium and phosphate (pH 7.4, 80° Celsius). As a result of this process, nucleation of the calcium phosphate as calcium-deficient HA (similar to the process of bone mineralization) on the metal surface will take place. The PA technique reveals a pure, single, crystallized precipitated HA coating with a thickness of 20 μm in all layers of the porous-surfaced prosthesis. No other calcium phosphate phases are present with this type of coating technique.

Table 1. Preoperative Patient Data (Means and Standard Deviations)

Variables	PA Coated	Uncoated
Sex (F/M)	10/2	8/2
Age (years)	65 ± 8.3	62 ± 2,0
BMI	25 ± 4.3	26 ± 2.9
Knee Score[1]	39 ± 12.2	47 ± 15.2
Larsen grades[2]	1/3/2/4/1	0/5/0/4/0
Range of Motion	94° ± 17.5°	93° ± 18.9°
Mechanical Axis	183° ± 5.3°	185° ± 5.2°

[1]Hospital for Special Surgery Knee Score
F = Female; M = Male; BMI = Body mass index
[2] Presented numbers are the number of patients per Larsen grade (1 till 5)

In all TKA surgeries, PA porous-coated femoral components and full PA cemented patellar components were used. The femorotibial design is a biconcave polyaxial radiated design with elongated posterior condyles and is stabilized mediolaterally with two pegs. The anatomically shaped patella component articulates in a proximal elongated trochlear groove. The exchangeable ultra-high molecular weight (UHMW) PE insert with a minimum thickness of 11 mm was fixed with an anterior and posterior lipping mechanism on the tibial tray.

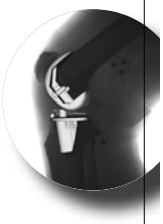
We used the same standard surgical procedure under tourniquet control in all patients. After a straight midline incision was made, the knee was opened by a medial arthrotomy. The tibial cutting surface was aligned extramedullary (prosthetic alignment perpendicular to the talocrural joint) and the distal femoral was cut intramedullary, aligned, and was adjusted to the femoral anatomy based on long, standing radiographs Soft tissue releases were done when necessary.

During surgery, three to eight tantalum beads (1 mm in diameter) were inserted in preselected places in the metaphyseal bone of the tibia. The insert of the tibial tray was manufactured with six tantalum balls. The locking mechanism between the insert and the tibial tray was pre-tested and showed no movement between the two parts.

After one day of bed rest, patients were allowed to walk using two crutches with partial weight bearing for 6 weeks. Antithrombotic prophylaxis was performed using acenocoumarol (oral acenocoumarol was combined with subcutaneous heparin until an INR [International Normalized Ratio] value between 2.5 and 3.5 was reached), after which acenocoumarol was continued for 6 weeks. At induction of anesthesia and postoperatively for 24 hours, patients received a total of three doses of cefamandole intravenously for infection prevention.

The patients were evaluated preoperatively, at 1 week after mobilization, and 3 months, 6 months, 1 year, and 2 years postoperatively. At each evaluation the clinical status was assessed and radiographs for RSA were made in supine position. Immediately after the operation, at the 1-year follow-up, and at the 2-year follow-up standard anteroposterior (AP) radiographs were taken with the patient standing. Lateral radiographs and axial radiographs of the patella were performed with the patient supine. The lateral and AP positions of the tibial and femoral components were measured as was the mechanical leg axis (Ewald, 1989).

The RSA setup consisted of two synchronized roentgen tubes positioned approximately 1.5 meter above a roentgen cassette (35x43 cm) at a 20° angle to the vertical. Both roentgen tubes simultaneously exposed the roentgen film. A calibration box made of Perspex™ was used to define the three-dimensional (laboratory) coordinate system. For this purpose 38 tantalum 1-mm markers were positioned in the lower plane of the box (fiducial markers). In order to calculate the focus position, 20 1-mm tantalum markers were positioned in the upper plane of the box (control markers).



Using a Vidar VXR-12 scanner (Vidar, Lund, Sweden), the radiographs were scanned at 150 dpi resolution and 8-bit grayscale resolution. The measurement of marker coordinates in the digitized radiographs, the 3-D reconstruction of the marker positions, and the micromotion analysis were done with RSA-CMS software (Medis, Leiden, The Netherlands), a software package that performs the RSA procedure automatically on digitized or digital radiographs (Vrooman et al., 1998). To assess the micromotion of the implants with a high accuracy, the bone markers need to be well fixed in the bone. Bone markers were defined as unstable when they moved more than 0.3 mm with respect to the other bone markers. Unstable markers were excluded from analysis.

The first RSA examination served as the reference baseline. All subsequent evaluations of micromotion were related to the relative position of the prosthesis with respect to the bone at the time of that evaluation. In 6 patients (10 knees; three from the PA group and seven from the uncoated group) the first RSA radiograph was not done within 5 days after surgery, but at 6 weeks postoperatively. As a consequence, in these patients, this radiograph was used as the reference baseline. Micromotion of the components was expressed as translation of the center of gravity of the prosthesis makers and rotation of the rigid body defined by the prosthesis markers about this center of gravity. Positive directions for translations along the orthogonal axes were transverse (lateral-medial), longitudinal (caudal–cranial), and sagittal (posterior–anterior). Positive directions for rotations about the coordinate axes were anterior tilt (transverse axis), internal rotation (longitudinal axis), and varus (sagittal axis).

The reproducibility of the RSA measurements was determined by means of replicate examination of 10 patients (Table 2). Replicate examination consisted of two RSA examinations of the same patient within about 10 minutes of each other. Because of the short time interval between these two radiographs, the assumption is made that the implant did not migrate between these two exposures relative to the surrounding bone. By comparing these two radiographs, the accuracy of the micromotion parameters can be assessed (Ranstam et al., 2000; Ryd et al., 2000).

Outcome measures used in this study to discriminate between the two groups were RSA results after two years follow-up, radiographic measurements and clinical scores (HSS). The observers were blinded to the results.

Table 2. Accuracy of the RSA Measurements Based on Double Examinations*

Component	Translation (mm)			Rotation (°)		
	Trans[1]	Long[1]	Sag[1]	Trans[2]	Long[2]	Sag[2]
Stem	0.132	0.126	0.335	0.426	0.511	0.247

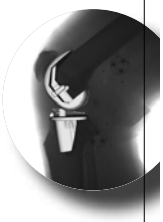
*Presented numbers are the upper limits of the 95% CI (N = 10)
[1]Trans = Transverse plane (medial-lateral); Long = Longitudinal plane (caudal-cranial or subsidence); Sag = Sagittal plane (posterior-anterior)
[2]Trans = Transverse plane (anterior tilt); Long = Longitudinal plane (internal rotation); Sag = Sagittal plane (varus rotation)

For comparison of the mean values of the two groups, a nonparametric Mann–Whitney U test was used. In order to explore the effects of the two types of fixation on the amount of micromotion after 2 years, a linear regression was used with migration at the 2-year follow-up as the dependent variable and the fixation type and the baseline examination (directly postoperative or 6 weeks postoperative) as covariables. Levene's test for homogeneity of variance was used to determine the differences of the group variances in the micromotion data. For all analyses, significance was determined by a p value of less than 0.05. All statistical analyses were performed using a commercial software package SPSS 12.0 (Chicago, IL, US).

9.3 Results

Follow-up clinical results (HSS score), and range of motion (ROM) were similar between the two groups (Table 3). The knee prosthesis of the patient who died showed no radiographic signs of loosening at 1-year follow-up.

Routine radiographs of the knees revealed no radiolucent lines of 2 mm or more around the tibial, femoral or patellar component in any knees of the two groups at the 2-year follow-up evaluations. Radiolucent lines with a maximum of 1 mm were seen in eight uncoated tibial components, whereas in the PA group no radiolucent lines beneath the tibial tray were detected. Two of the eight uncoated knees showed 4 zones with nonprogressive radiolucencies (medial/lateral/anterior and posterior) with a maximum of 1 mm between the tibial base plate and the tibial bone. Sclerotic



lines around the keel of the tibial tray were seen in two knees, one in the PA group and one in the uncoated group.

Table 3. Clinical results during follow-up (Means and Standard Deviations).

Variables	PA Coated		Uncoated	
	6 Weeks[1]	2 Years[1]	6 Weeks[1]	2 Years[1]
HSS Knee Score	77 ± 19.3	88 ± 10.2	80 ± 9.0	88 ± 9.7
Range of Motion	90° ± 16.7	108° ± 18.4	86° ± 9.9	107° ± 18.3

[1]Postoperative time points
HSS = Hospital for Special Surgery

The average mechanical leg axis was similar for the two groups at the 2-year follow-up. The radiographic orientation of the components showed no differences between the two groups (Table 4). Cortical rim support of the tibial base plate judged on plain AP and lateral radiographs was considered insufficient in four knees (two from the PA group and two from the uncoated group). However, these four knees showed no radiographic evidence of radiolucencies around the tibial component.

Table 4. Mechanical Axis and Component Orientation (Means and Standard Deviations)*

Variables	PA Coated	Uncoated
Mechanical Axis	179° ± 2.5°	180° ± 3.0°
Femur (AP)	98° ± 2.5°	99° ± 1.2°
Femur (Lateral)	1° ± 2.8°	3° ± 3.1°
Tibia (AP)	88° ± 2.0°	88° ± 1.5°
Tibia (Lateral)	86° ± 2.4°	86° ± 1.9°

*Results are from the 2-year follow-up examinations
AP = Anteroposterior

Results of the replicate RSA examinations showed that the upper limits of the 95% confidence intervals of the translation and rotation variables (Table 1) were below 0.35 mm for translations and below 0.51 for rotations. Confounding of the difference in baseline examination had no influence on migration along the three orthogonal

axes. This indicates there was no difference between the delayed baseline examination groups on the total amount of micromotion from 6 weeks postoperatively up to the 2-year examination compared with the postoperative RSA examination.

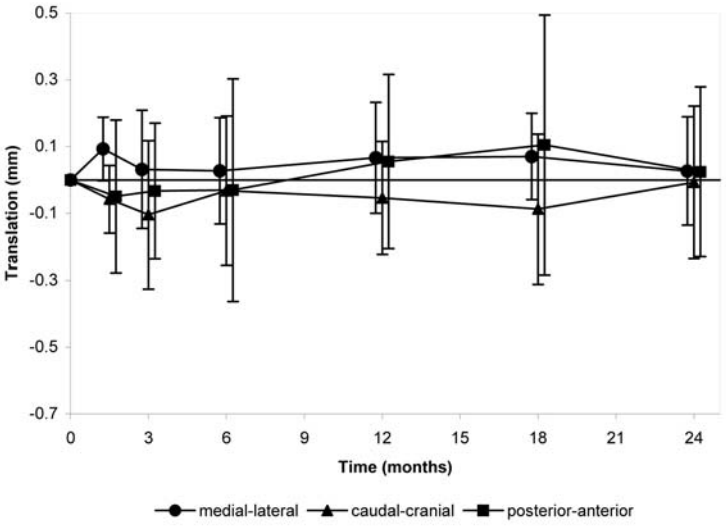


Figure 1A. Translations of the PA coated tibial components along the three orthogonal axes (mean and standard deviation).

We observed no difference in migration patterns or in the translations and rotations. Power analysis showed that a statistical power was reached of 0.68. For the PA-coated tibial components, these results were 0° ± 0.23 mm (95% CI, -0.45 to 0.45 mm) and -0.2° ± 0.38° (95% CI, -0.74° to 0.54°), respectively (Figure 1A, Figure 2A and Table 5). For noncoated components, mean subsidence was -0.15 ± 0.47 mm (95% confidence interval [CI], -1.07 to 0.77 mm) and mean valgus rotation was -0.6° ± 0.49° (95% CI, -1.56° to 0.36°) respectively (Figure 1B, Figure 2B and Table 5). However, the uncoated components had a higher ($p = 0.007$) variance in subsidence compared with the PA-coated components. Both groups showed also a high variance in anterior tilting of the components (range for the PA group, -1.44° to 1.57°; range for the uncoated group, -0.90° to 2.52°). No correlation was found between the postoperative mechanical leg axis of all pooled data and varus or valgus rotations of the components.

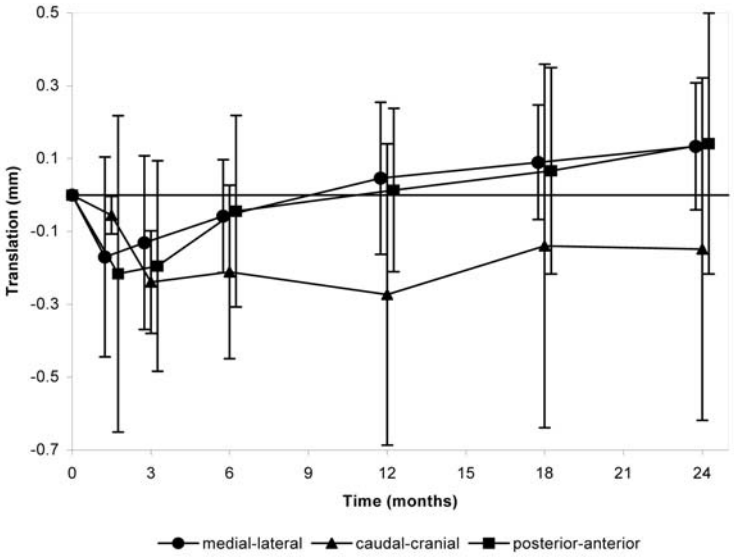


Figure 1B. Translations of the uncoated tibial components along the three orthogonal axes (mean and standard deviation).

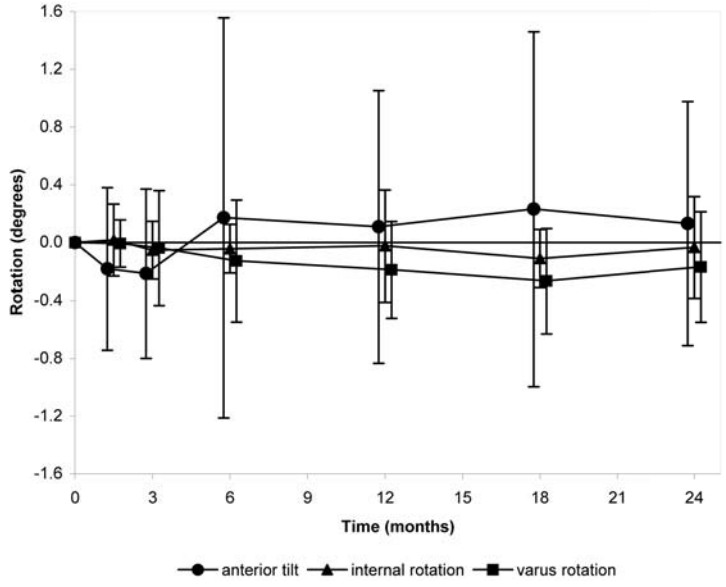


Figure 2A. Rotations of the PA coated tibial components about the three orthogonal axes (mean and standard deviation).

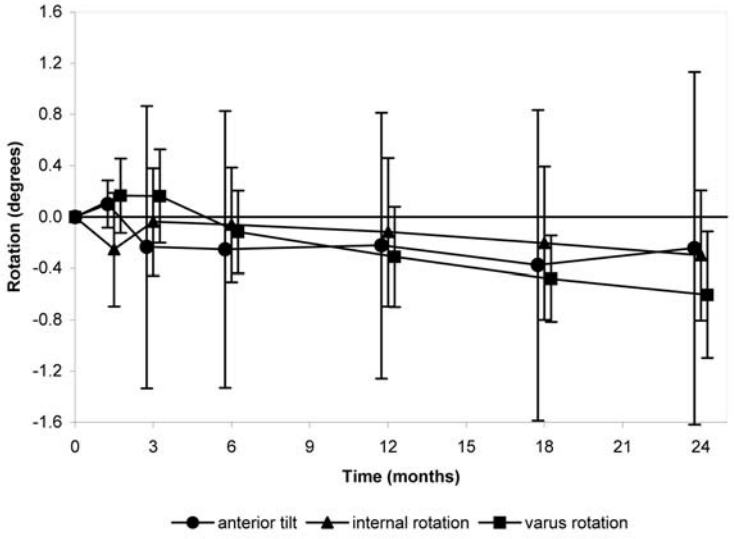
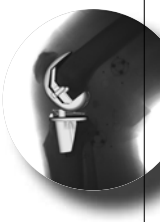


Figure 2B. Rotations of the uncoated tibial components about the three orthogonal axes (mean and standard deviation).

Table 5. Migration of the PA-Coated and Uncoated Tibial Components (Means and Standard Deviations)*

Variables		PA Coated	Uncoated
Translation (mm)	Medial-Lateral	0.027 ± 0.162	0.134 ± 0.174
	Caudal-Cranial	-0.007 ± 0.229	-0.149 ± 0.470
	Posterior-Anterior	0.025 ± 0.254	0.141 ± 0.358
Rotation (degrees)	Anterior Tilt	0.133 ± 0.844	-0.243 ± 1.374
	Internal Rotation	-0.034 ± 0.351	-0.299 ± 0.507
	Varus Rotation	-0.169 ± 0.381	-0.605 ± 0.492

*Results are from the 2-year follow-up examinations



9.4 Discussion

We hypothesized augmentation of a calcium phosphate coating (PA) to cementless tibial components in a RA patient group would enhance the fixation of these components when compared to cementless, non-coated components. The addition of a calcium phosphate coating to the currently studied TKA gave less variability in prosthesis migration. We were unable to support the hypothesis although noted a trend suggesting addition of a calcium phosphate coating (i.e. PA) might decrease tibial component migration. This might be because of the overall high variability of the mean migration in these patients with RA, which might be a reflection of the variability in their bone quality. Prevalence of RA in the general population is low. In the Swedish knee arthroplasty register (Robertsson et al., 2001), patients with RA made up 10% of the total of 45,000 knee prostheses. Authors of a study in the United States showed a prevalence of only 3.6% (4533 patients) of patients with RA in a total of 125,000 TKAs done in 2000 (Nizar et al., 2005). Patients with RA differ from patients with osteoarthritis patients not only because of the systemic character of their disease (e.g., more osteoporosis), but generally they also are younger.

We note several limitations. Most importantly is the limited number of patients. A power analysis before the study showed, based on data reported in a previous RSA study (Nelissen et al., 1998), that a significant difference in subsidence of 0.3 mm could be observed when 12 patients were included in each group. The power analysis after conducting the study showed a statistical power of 0.68 because of the slightly larger standard deviation than previously assumed. The loss of 7 patients in the uncoated group and 3 in the PA group at the 5 day RSA baseline would intuitively lead to a reduction of the variability and the mean subsidence resulting in an underestimation of the differences between the two groups. However, statistical analysis using a regression analysis showed that there was no effect of delaying the baseline examination to 6 weeks.

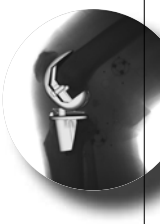
Although acrylic bone cement is the primary load-bearing material used for the attachment of orthopaedic devices to adjoining bone, a potential negative effect is its known degradation during long-term follow-up (Hoffmann ett al., 1997) and stimulation of osteolysis caused by particulate debris (Brooks et al., 2000; Sabokbar

et al., 1997; Shardlow et al., 2003; Wimhurst et al., 2001). Enhancement of bone ingrowth into cementless knee prostheses using calcium phosphate coatings has been advocated (Nelissen et al., 1998; Nilsson et al., 1999; Søballe et al., 1993). Furthermore, the sealing effect of these coatings for the prosthetic interface from particulate debris also would be advantageous (Rahbek et al., 2001).

A potential negative effect of calcium phosphate coatings is delamination and third-body wear (Wang et al., 1997). Thick calcium phosphate layers (greater than 100 μm) have a tensile bond strength of only 35 MPa with subsequent risk for delamination (Nilsson et al., 1994; Røkkum et al., 2002). The Duracon prosthesis, with its double-layer beaded surface, is coated with a PA coating at a mean thickness of 20 μm with a tensile bond strength of 65 MPa. In addition to the bioactive coating, prosthesis design also is important to implant survival in cementless prostheses. The Duracon knee has a risk ratio for revision of 1.05 compared with its predecessor, the PCA cementless uncoated knee, which had a risk ratio for revision of 2.28 (Furnes et al., 2002; Robertsson et al., 2001). These differences probably are accounted for because of design changes of the tibial base plate in these two devices.

Prosthetic failure also is related to insufficient bone contact. The supportive cortical bone in healthy knees is 6% of the total tibial surface and the cancellous ingrowth areas are 18% (Bloebaum et al., 1994). Bone quality in the patients with RA generally is reduced; they have thinner cortical bone and reduced cancellous bone. Migration results of the PA group in this study and in other studies in which different calcium phosphate coatings were used (Nelissen et al., 1998; Nilsson et al., 1994; Oliver et al., 2005) are favorable. Furthermore, no effect of bone quality on migration (Tagil et al., 2003) or revision rate (Therbo et al., 2003) was found. Although in our series the differences in migration between uncoated and PA groups did not differ, we found less variability in PA group. A trend could be detected toward a more stable fixation in the PA group.

Prosthetic position also influences TKA survival (Bargren et al., 1993; Ecker et al., 1987). However, we could not find a correlation between prosthetic malalignment (< 176°, > 184°), and increased micromotion after two years, probably because of absence of extreme outliners in the postoperative mechanical axes in this study.



Authors of two RSA studies comparing migration results between uncoated, HA-coated, and cemented tibial implants showed a higher rate of migration in the uncoated groups compared with the HA and the cemented implants in patients with OA and RA (Nelissen et al., 1998; Nilsson et al., 1999). After a settling period, stabilization of the HA-coated implants occurred. Although the PA-coated implants we studied tended to act similarly to these HA-coated implants, the variation in migration in the current study is greater (Nelissen et al., 1998; Nilsson et al., 1999; Onsten et al., 1998). Initial migration during the first 3 to 6 months is highest; after that the PA components tend to stabilize. Although others showed bone ingrowth continues up to 9 months after implantation (Hughes et al., 2003), the micromotion curve suggests earlier mechanical stability. The uncoated groups show progressive micromotion along the orthogonal axes throughout the 2-year follow-up. It has not been determined yet whether this results in long-term failure. The ability of calcium-phosphate-coated implants to sustain the forces that threaten fixation early after implantation and to remain stable in the longer term is supported with excellent 10-year survival data (90–98% survival) in patients with RA (Illgen et al., 2004; Robertsson et al., 2001; Watanabe et al., 2004; Weir et al., 1996; Whiteside, 1994; Wright et al., 2004).

Although we noted no differences in migration between uncoated and PA-coated implants, we saw a trend for less subsidence and anterior tilting in patients with PA-coated implants. We observed lower variance in migration when PA-coated implants were used. Different implant designs will have different impacts on migration. The influence of these individual prosthetic designs can be evaluated accurately with RSA.

References

Bargren JH, Blaha JD, Freeman MAR. Alignment in total knee arthroplasty. Correlated biomechanical and clinical observations. *Clin Orthop Relat Res* 1993; 173: 178-183.

Bloebaum RD, Bachus KN, Mitchell W, Hoffman G, Hofmann AA. Analysis of the bone surface area in resected tibia. Implications in tibial component subsidence and fixation. *Clin Orthop Relat Res* 1994; 309: 2-10.

Brooks RA, Sharpe JR, Wimhurst JA, Myer BJ, Dawes EN, Rushton N. The effects of the concentration of high-density polyethylene particles on the bone-implant interface. *J Bone Joint Surg* 2000; 82B: 595-600.

Ecker ML, Lotke PA, Windsor RE, Cella JP. Long-term results after total condylar knee arthroplasty. *Clin Orthop Relat Res* 1987; 216: 151-158.

Ewald F. The knee society total knee arthroplasty roentgenographic evaluation and scoring system. *Clin Orthop Relat Res* 1989; 248: 9-12.

Furnes O, Espehaug B, Lie SA, Vollset SE, Engesaeter LB, Havelin LI. Early failures among 7,174 primary total knee replacements. *Acta Orthop Scand* 2002; 73: 117-129.

Hughes KF, Ries MD, Pruitt LA. Structural degradation of acrylic bone cements due to *in vivo* and simulated aging. *J Biomed Mater Res A* 2003: 65: 126-35.

Hoffmann AA, Bloebaum RD, Bachus KN. Progression of human bone ingrowth into porous-coated implants. Rate of bone ingrowth in humans. *Acta Orthop Scand* 1997; 68: 161-166.

Illgen R, Tueting J, Enright, et al. Hybrid total knee arthroplasty: a retrospective analysis of clinical and radiographic outcomes at average 10 years follow-up. *J Arthroplasty* 2004; 19: 95-100.

Insall JN, Ranawat CS, Aglietti P, Shine J. A comparison of four models of total knee-replacement prostheses. *J Bone Joint Surg [Am]* 1976; 58-A: 754-65.

Nelissen RG, Valstar ER, Rozing PM. The effect of hydroxyapatite on the micromotion of total knee prostheses. A prospective, randomized, double-blind study. *J Bone Joint Surg* 1998; 80A: 1665-1672.

Nelissen RGHH. The impact of total joint replacement in rheumatoid arthritis. *Best Pract Res Clin Rheumatol* 2003; 17: 831-846.

Nilsson KG, Cajander S, Kärrholm J. Early failure of hydroxyapatite-coating in total knee arthroplasty. *Acta Orthop Scand* 1994; 65: 212-214.

Nilsson KG, Kärrhlom J, Carlsson L, Dalen T. Hydroxyapatite coating versus cemented fixation of the tibial component in total knee arthroplasty: Prospective randomized comparison of hydroxyapatite-coated and cemented tibial components with 5-year follow-up using radiostereometry. *J Arthroplasty* 1999; 14: 9-20.

Nizar N, Barrett J, Katz JN, Baron JA, Wright J, Losina E. Epidemiology of total knee replacement in the United States Medicare population. *J Bone Joint Surg* 2005: 87-A: 1222-1228.

Oliver MC, Keast-Butler OD, Hinves BL, Shepperd JAN. A hydroxyapatite-coated Insall-Burstein II total knee replacement. *J Bone Joint Surg* 2005; 87: 478-482.

Onsten I, Nordqvist A, Carlsson AS, Besjakov J, Shott S. Hydroxyapatite augmentation of the porous coating improves fixation of tibial components. A randomised RSA study in 116 patients. *J Bone Joint Surg* 1998; 80B: 417-425.

Rahbek O, Overgaard S, Lind M, Bendix K, Bünger C, Søballe K. Sealing effect of hydroxyapatite coating on peri-implant migration of particles. An experimental study in dogs. *J Bone Joint Surg* 2001; 83B: 441-447.

Ranstam J, Ryd L, Onsten I. Accurate accuracy assessment: Review of basic principles. *Acta Orthop Scand* 2000; 71: 106-108.

Robertsson O, Knutson K, Lewold S and Lidgren L. The Swedish knee arthroplasty register 1975-1997. An update with special emphasis on 41, 223 knees operated on in 1988-1997. *Acta Orthop Scand* 2001; 72: 503-513.

Røkkum M, Reigstad A, Johansson CB. HA particles can be released from well-fixed HA-coated stems. Histopathology of biopsies from 20 hips 2-8 years after implantation. *Acta Orthop Scand* 2002; 73: 298-306.

Ryd **L, Albrektsson BE, Carlsson L, et al.** Roentgen stereophotogrammetric analysis as a predictor of mechanical loosening of knee prosthesis. *J Bone Joint Surg* 1995; 77B: 377-383.

Ryd L, Yuan X, Löfgren H. Methods for determining the accuracy of radiostereometric analysis (RSA). *Acta Orthop Scand* 2000; 71: 403-408.

Sabokbar A, Fujikawa Y, Murray DW, Athanasou NA. Radio-opaque agents in bone cement increase bone resorption. *J Bone Joint Surg* 1997; 79B: 129-134.

Shardlow DL, Stone MH, Ingham E, Fisher J. Cement particles containing radio-opacifiers stimulate pro-osteolytic cytokine production from a human monocytic cell line. *J Bone Joint Surg* 2003; 85B: 900-905.

Søballe K, Hansen ES, Brockstedt-Rasmussen H, Bünger C. Hydroxyapatite coating converts fibrous tissue toe bone around loaded implants. *J Bone Joint Surg* 1993; 75 B: 270-278.

Tagil M, Hanssson U, Sigfusson R et al. Bone morphology in relation to the migration of porous-coated anatomic knee arthroplasties: A roentgen stereophotogrammetric and histomorphometric study in 23 knees. *J Arthroplasty* 2003: 18: 649-653.

Therbo M, Petersen MM, Varmarken JE, Olsen CA, Lund B. Influence of preoperative bone mineral content of the proximal tibia on revision rate after uncemented knee arthroplasty. *J Bone Joint Surg* 2003; 85B: 975-979.

Vrooman HA, Valstar ER, Brand GJ, Admiraal DR, Rozing PM, Reiber JH. Fast and accurate automated measurements in digitized stereophotogrammetric radiographs. *J Biomech* 1998; 31: 491-498.

Wang W, Ferguson DJ, Quinn JM, Simpson AH, Athanasou NA. Biomaterial particle phagocytosis by bone-resorbing osteoclasts. *J Bone Joint Surg* 1997; 79B: 849-856.

Watanabe H, Akizuki S, Takizawa T. Survival analysis of a cementless, cruciate retaining total knee arthroplasty. Clinical and radiographic assessment 10 to 13 years after surgery. *J Bone Joint Surg* 2004; 86B: 824-829.

Weir DJ, Moran CG, Pinder IM. Kinematic condylar total knee arthroplasty. *J Bone Joint Surg* 1996; 78B: 907-911.

Whiteside LA. Cementless total knee replacement. Nine- to 11 year results and 10-year survivorship analysis. *Clin Orthop Relat Res* 1994; 309: 185-192.

Wimhurst JA, Brooks RA, Rushton N. The effects of particulate bone cements at the bone-implant interface. *J Bone Joint Surg* 2001; 83B: 588-592.

Wright RJ, Sledge CB, Poss R, Ewald FC, Walsh ME, Lingard EA. Patient-reported outcome and survivorship after Kinemax total knee arthroplasty. *J Bone Joint Surg* 2004; 86A: 2464-2470.