Influence of pre-operative bone mineral content of the proximal tibia on revision rate after uncemented knee arthroplasty

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Between 1986 and 1991, 106 patients (127 knees) underwent uncemented knee arthroplasty for osteoarthritis. There were 106 total knee arthroplasties and 21 medial unicompartmental knee arthroplasties. The arthroplasties were evaluated for aseptic loosening during the year 2000. For total arthroplasty we used 77 porous-coated anatomic prostheses and 29 press-fit condylar prostheses. The mean bone mineral content of the proximal tibia, measured the day before surgery using dual-photon absorptiometry was 5.48 g/cm for the porous-coated anatomic prostheses which were revised for aseptic loosening ($n = 9$). This was significantly higher ($p = 0.02$) than the mean of 4.33 g/cm for those which were not revised. Values for the two revised press-fit condylar knees (4.78 and 4.93 g/cm) were above the mean value (4.23 g/cm) for those which were not revised. We found no statistically significant ($p = 0.38$) difference between the bone mineral content of the 12 revised and nine unrevised unicompartmental arthroplasties. Low trabecular bone quality, measured as the pre-operative bone mineral content of the proximal tibia, was not a predictor for later revision surgery following uncemented total knee or unicompartmental knee arthroplasty.

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The use of uncemented knee arthroplasty is declining. It is generally accepted that uncemented techniques should be reserved for young patients with good bone quality.¹⁻³ The scientific data to support this assumption are, however, rela-

tively sparse. The amount of bone ingrowth for fixation of an uncemented implant depends on primary stability, while for unstable implants, fixation is obtained mainly by fibrous tissue ingrowth.⁴ In an experimental biomechanical study using a foam model of the proximal tibia, Lee, Volz and Sheridan,⁵ found that the mechanical stability of uncemented tibial components related directly to the density of the foam and was greatly enhanced in poor quality foam by the use of bone cement. The most rigid uncemented fixation was achieved using four peripherally placed cancellous screws, while the addition of a central stem added stability only with low density foam.

The quality of the periprosthetic bone, as judged from the patient's history, physical examination and plain radiographs of the knee is often used to determine the mode of fixation in arthroplasty. It is well known, however, that an accurate and precise determination of bone mineral content (BMC) or density (BMD) from plain radiographs is not possible.^{6,7} Measurements of BMC or BMD by dual photon or X-ray absorptiometry can provide non-invasive evaluations *in vivo* of the mechanical properties of the trabecular bone of the proximal tibia. It is, thus, possible to obtain a quantitative measure of the bone's biomechanical characteristics before knee arthroplasty.^{8,9}

In order to establish if the pre-operative quality of the periprosthetic bone is an important determinant for later revision surgery, we examined the relationship between the pre-operative measurements of BMC of the proximal tibia and the ten-year survival after uncemented total knee arthroplasty (TKA) and medial unicompartmental knee arthroplasty (UKA).

Patients and Methods

We included 106 patients (127 knees) who underwent an uncemented knee arthroplasty for osteoarthritis in our study (Table I). The operations were undertaken between 1986 and 1991. In 77 a porous-coated anatomic (PCA) TKA (Howmedica Inc, Rutherford, New Jersey) whose tibial component did not have a central stem was used and in 29 a press-fit condylar (PFC) TKA (Johnson & Johnson Orthopaedics, Raynham, Massachusetts), whose tibial component did have a central stem was used and in 21 knees a medial PCA (Howmedica) UKA was used.

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Table I. Pre-operative details of the 106 patients (127 knees) before knee arthroplasty and their status at follow-up

	Type of prosthesis			
	PCA	PFC	TKA (PCA + PFC)	PCA UKA
Operated knees (number)	77	29	106	21
Female	56	19	75	13
Male	21	10	31	8
Mean age in years (range)	69 (34 to 85)	71 (54 to 85)	70 (34 to 85)	69 (55 to 80)
Mean BMC g/cm (range)	4.46 (1.95 to 8.49)	4.27 (1.22 to 8.91)	4.41 (1.22 to 8.91)	4.13 (1.95 to 6.66)
BMC				
T-score - Mean	-1.20	-1.45	-1.27	-1.64
- Range	-3.5 to 1.99	-4.08 to 2.37	-4.08 to 2.37	-3.35 to 1.05
- 95% CL	-1.47 to 0.93	-2.08 to -0.82	-1.52 to -1.01	-2.12 to -1.16
Z-score - Mean	0.60	0.28	0.52	-0.24
- Range	-1.84 to 2.84	-2.50 to 3.08	-2.50 to 3.08	-1.20 to 0.70
- 95% CL	0.31 to 0.89	-0.41 to 0.97	0.25 to 0.79	-0.67 to 0.19
Alive at follow-up (no revision)				
Number of patients	40	9	49	7
Mean years after surgery (range)	11.26 (9.58 to 14.08)	12.41 (12.00 to 12.66)	11.47 (9.58 to 14.08)	12.57 (12.16 to 13.33)
Died before follow-up (no revision)				
Number of patients	25	18	43	2
Mean years after surgery (range)	6.08 (0.08 to 11)	5.3 (0.08 to 10.4)	5.75 (0.08 to 11)	3.33 + 8.41
Revision of femoral, tibial or patellar component				
Number of knees	9	2	11	12
Percent revised	11.7	6.9	10.4	57.1
Mean years after initial surgery (range)	4.6 (0.66 to 10.25)	6.25 + 7.25	4.99 (1.16 to 9.75)	4.9 (1.58 to 8.66)
Tibial polyethylene insert replaced				
Number of knees	3	0	3	0
Percent revised	3.9		2.8	
Mean years after initial surgery (range)	5.19 (0.66 to 10.25)		5.19 (0.66 to 10.25)	

On the day before surgery all patients had a measurement of the BMC of the proximal tibia using dual-photon absorptiometry (DPA) with radiation peaks of 44 and 100 KeV from a Gadolinium-153 source (200 mCi) in a custom-made Gammatec knee scanner (GT-50 tibia-1a, Gammatec A/S, DK-3500 Værløse, Denmark). This scanner was specially designed for bone mineral measurements of the proximal tibia. The scans were made transverse to the axis of the bone in the coronal plane of the proximal tibia using a pixel size of 2 x 2 mm and a scan speed of 4 to 6 mm/s as previously described.¹⁰ On the computerised scan plot of the proximal tibia, a 0.8 cm wide region just below the subchondral plates was selected for measurements of BMC (Fig. 1). During surgery, the tibia was divided just above or through the most proximal part of this area of the bone. Previously published normative data for BMC of the proximal tibia in 102 healthy women aged between 20 and 86 years were used for the calculation of the Z-score for the 88 knees in women.¹¹ Normative data in ten young, healthy women with a mean age of 32 years (24 to 44) and ten healthy men with a mean age of 31 years (24 to 34) were used for the calculation of the T-score for the 127 knees undergoing surgery.

During 2000, we evaluated the revision rate for these 127 arthroplasties. Using a nationwide register (Det Grønne System; Scandanavian Healthcare Informatics A/S, Aarhus N, Denmark) all patients, including those who had died, were checked for possible admissions to a department of orthopaedic surgery in Denmark at any time after surgery. If a

patient had been admitted, sufficient information was collected from medical records in order to allow us to decide whether or not the arthroplasty had been revised. This included the date and reason for the revision and which components were loose. In all patients who underwent further surgery to the affected knee, with replacement of the femoral, tibial or patellar component, the operation was recorded as a revision. It was not considered to be a revision if only the tibial polyethylene insert was replaced at the second operation. No arthroplasty was revised because of deep infection. Patients who died during the follow-up period with the prosthesis *in situ* were recorded as not revised.

Statistical analysis. We used Kaplan-Meier survival analysis with calculation of the cumulative survival rate for the three different knee prostheses. Using normative data for BMC the average T- and Z-scores with the 95% confidence limits (95% CL) were calculated. The Student's *t*-test for unpaired data was used for evaluating the differences between the pre-operative BMC (and T-scores) in revised knees and those with the arthroplasty still *in situ*. Results are given as the mean and total range. We considered *p* values < 0.05 as significant. The study had ethical approval.

Results

TKA using PCA prostheses. Of 77 knees, 25 patients (25 knees) had died at a mean of 6.08 years (0.08 to 11) after the operation, without having had further surgery to the knee.

Fig. 1

Scan plot of the proximal tibia from a patient with osteoarthritis of the knee. Between the two horizontal lines the region of interest selected for BMC measurements, 0.8 to 1.6 cm below the subchondral planes is shown.

Three knees had the tibial polyethylene insert changed at a second operation and nine had a revision with either the patellar, tibial or femoral component exchanged. This gave a cumulative survival rate of 85.4% (Table I, Fig. 2). At revision surgery five knees had a loose tibial component and in one the patellar component was also loose. In two knees all components were loose and in two only the patellar component was loose. From the pre-operative BMC of the prox-

Fig. 2

Kaplan-Meier survival analysis of the three arthroplasties. Three knees where only the tibial insert was replaced are not recorded as being revised.

imal tibia the calculated T- ($n = 77$) and Z-scores ($n = 56$) were -1.20 and 0.60 , respectively (Table I). The mean BMC (5.48 g/cm) of the nine revised knees was significantly higher ($p = 0.02$) than that of the unrevised knees (4.33 g/cm) (Table II).

TKA using PFC prostheses. Of 29 knees, 18 patients (18 knees) had died at a mean of 5.3 years (0.08 to 10.4) after the operation without having had further surgery to the knee. Two had a revision, one with loosening of all components, one in which only the patellar component was loose, and the cumulative survival rate was 89.4% (Fig. 2). From the pre-operative BMC of the proximal tibia the calculated T- ($n = 29$) and Z-scores ($n = 19$) were -1.45 and 0.28 , respectively (Table I). The BMC of the two revised knees (4.78 and 4.93 g/cm) was higher than that of the unrevised knees (4.23 g/cm) (Table II).

UKA. Of 21 knees, two patients (2 knees) had died, 3.33 and 8.4 years after the operation, without having had further surgery to the knee (Table I). From the pre-operative BMC of the proximal tibia, the calculated T- ($n = 21$) and Z-scores ($n = 13$) were -1.64 and -0.24 , respectively (Table I). The UKA had a low cumulative survival rate of 39.5% (Fig. 2). All the revised UKAs were complete revisions with the knee being converted to a TKA. The mean BMC (4.39 g/cm) of the revised knees was higher than for the unrevised knees (3.77 g/cm) although, as shown in Table II, this was not statistically significant ($p = 0.38$).

Discussion

We found that the mean pre-operative BMC of the proximal tibia in 77 knees which underwent an uncemented PCA TKA was significantly higher in those who underwent revi-

Table II. Comparison of the pre-operative mean BMC (g/cm) of the proximal tibia between revised and unrevised knee arthroplasties

Type of prosthesis	Implant not revised	Implant revised	p value
PCA			
Mean BMC in g/cm (range)	4.33 (1.95 to 8.49)	5.48 (3.48 to 7.78)	0.02
Mean T-score (range)	-1.29 (-5.52 to 1.99)	-0.49 (-3.01 to 1.25)	0.06
Number	68	9	
Female	52	4	
Male	16	5	
Mean age in years (range)	70 (35 to 85)	61 (34 to 75)	
PFC			
Mean BMC (range)	4.23 (1.22 to 8.91)	4.86 (4.78 to 4.93)	0.68
Mean T-score (range)	-1.52 (-4.08 to 2.37)	-0.45 (-0.52 to -0.37)	0.38
Number	27	2	
Female	17	2	
Male	10	0	
Mean age in years (range)	72 (54 to 85)	69 (69 to 69)	
TKA (PCA + PFC)			
Mean BMC (range)	4.30 (1.22 to 8.91)	5.37 (3.48 to 8.25)	0.04
Mean T-score (range)	-1.37 (-5.52 to 2.37)	-0.48 (-3.01 to 1.25)	0.04
Number	95	11	
Female	69	6	
Male	26	5	
Mean age in years (range)	71 (35 to 85)	62 (34 to 75)	
UKA			
Mean BMC (range)	3.77 (1.95 to 6.23)	4.39 (2.08 to 6.66)	0.38
Mean T-score (range)	-1.93 (-3.35 to -0.29)	-1.42 (-3.22 to 0.14)	0.28
Number	9	12	
Female	6	7	
Male	3	5	
Mean age in years (range)	71 (60 to 80)	67 (55 to 76)	

sion surgery for aseptic loosening than in those knees which were not revised during the first decade after surgery. The same trend was observed for the 29 PFC TKAs. The cumulative survival rate for the PCA TKAs was similar to that in previous reports.^{12,13} The PFC TKAs had a similar cumulative survival rate. The cumulative survival rate for the UKAs was poor, but not markedly so when compared with previous reports using this prosthesis.^{12,14} The pre-operative BMC in the 21 UKAs showed no significant difference in the mean BMC between revised and unrevised knees. It thus appears that the pre-operative BMC was not a significant determinant for later revision surgery in UKA.

According to the WHO definition for the diagnosis of osteoporosis, patients with bone mineral values calculated as T-scores below -2.5 SD are classified as osteoporotic while those between -2.5 SD and -1 SD are classified as osteopenic.¹⁵ In our study, the pre-operative BMC of patients who received either a TKA or a UKA had a wide range of values, although the mean T-score fell within the limits of the WHO definition of osteopenia. Previous studies have shown that patients who suffer from osteoarthritis tend to have a normal or slightly increased bone mass.^{16,17} Whether or not the BMC is increased in a knee affected by osteoarthritis remains unclear. Using the same technique and site of measurement as our study, Petersen et al¹¹ found that the pre-operative BMC in the knees of women who were awaiting TKA for osteoarthritis was significantly elevated. Karvonen et al,¹⁷ using dual energy X-ray absorptiometry (DEXA) found a decreased BMD in various

subchondral sites at the knee in patients who suffered from mild osteoarthritis. The mean Z-score in our study indicated that the pre-operative BMC of the proximal tibia in osteoarthritic knees when compared with age-matched normal knees, was the same, or significantly higher than healthy age-matched women for both the TKA and UKA groups.

In a prospective study of 346 knees, Baldwin and Rubinstein¹⁸ assessed the effect of bone quality on the outcome after uncemented TKA. Intra-operatively, the surgeon assessed the quality of the bone. This was undertaken without any biomechanical or densitometric tests. The mean follow-up was 48 months. No statistically significant differences between knees with good and poor bone quality and the frequency of radiolucent zones, post-operative complications and reoperations were found. The follow-up was too short to establish a possible effect of bone quality on the frequency of revision, but as the revision rate increases significantly with time, it is possible that longer follow-up might reveal a possible effect of bone quality.^{18,19}

Two previous studies have investigated the relationship between pre-operative, quantitative, densitometric measurements of bone mineral at the proximal tibia and the migration of an uncemented tibial component as judged by radiostereometric analysis (RSA).^{20,21} The change in maximal total point movement (MTPM) of the tibial component more than one year after operation is generally accepted as the best predictor for later mechanical loosening.²² Petersen et al²⁰ measured the BMD of the proximal tibia using DPA. They followed 19 uncemented TKAs with RSA of the tibial

component for three years. Their results were similar to ours with a negative and significant relationship between the MTPM more than one year after operation and the pre-operative BMD was found. This relationship was only marginally significant, however, and almost all migration had taken place within the first year. There were no continuously migrating components. Li and Nilsson²¹ measured the pre-operative BMD of the proximal tibia using DEXA and followed 14 uncemented and ten cemented TKAs with RSAs for two years. They found no significant relationship between the MTPM one to two years after surgery and the BMD of the proximal tibia for either uncemented or cemented TKA. Relatively few TKAs were included in the study and no prosthesis had a pattern of migration which suggested a risk of subsequent aseptic loosening.

Previous experimental studies have shown that the design of the PCA TKA has the poorest mechanical stability when compared with other uncemented tibial implants.^{23,24} According to the foam model study by Lee et al⁵ this implant could be expected to have an even poorer mechanical stability in knees with a low BMC of the proximal tibia. In our study, however, the PCA TKAs which were revised for aseptic loosening had significantly higher BMC values when compared with the unrevised TKAs.

It is well known that the BMC of the proximal tibia, as in other parts of the skeleton, is influenced by several parameters including gender, age, the level of physical activity and periods of immobilisation due to musculoskeletal injuries.^{11,25,26} Knees with the highest BMC would probably be in young individuals with a high level of physical activity and, most frequently, men; these are also parameters which are recognised as risk factors for early aseptic loosening. In a study from the Swedish Knee Arthroplasty Register which evaluated 41 233 knee arthroplasties undertaken between 1988 and 1997, it was found that the older the patient, the lower the revision rate for aseptic loosening.¹⁹ However, identical revision rates for both men and women were found when TKA was undertaken for osteoarthritis.¹⁹ In our study the T scores, presented in Table II, show the same pattern for BMC when comparing revised and unrevised patients. We cannot be certain that the higher BMC in a TKA which has been revised for aseptic loosening is significantly affected by young age and a high level of physical activity. Low trabecular bone strength measured as the pre-operative BMC of the proximal tibia did not seem to be a predictor for subsequent revision surgery due to mechanical loosening after uncemented TKA or UKA.

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