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The importance of adequate stem anteversion for rotational stability in cemented total hip replacement
A RADIOSTEREOMETRIC STUDY WITH TEN-YEAR FOLLOW-UP

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Abstract

Progressive retroversion of a cemented stem is predictive of early loosening and failure. We assessed the relationship between direct post-operative stem anteversion, measured with CT, and the resulting rotational stability, measured with repeated radiostereometric analysis over ten years. The study comprised 60 cemented total hip replacements using one of two types of matt collared stem with a rounded cross-section. The patients were divided into three groups depending on their measured post-operative anteversion (< 10°, 10° to 25°, > 25°). There was a strong correlation between direct post-operative anteversion and later posterior rotation. At one year the < 10° group showed significantly more progressive retroversion together with distal migration, and this persisted to the ten-year follow-up. In the < 10° group four of ten stems (40%) had been revised at ten years, and an additional two stems (20%) were radiologically loose. In the 'normal' (10° to 25°) anteversion group there was one revised (3%) and one loose stem (3%) of a total of 30 stems, and in the > 25° group one stem (5%) was revised and another loose (5%) out of 20 stems. This poor outcome is partly dependent on the design of this prosthesis, but the results strongly suggest that the initial rotational position of cemented stems during surgery affects the subsequent progressive retroversion, subsidence and eventual loosening. The degree of retroversion may be sensitive to prosthetic design and stem size, but < 10° of anteversion appears deleterious to the long-term outcome for cemented hip prosthetic stems.

Introduction

Successful joint replacement surgery is associated not only with prosthetic design but also surgical technique. In recent years the biomechanical aspects of aseptic loosening in relation to stem anteversion, prosthesis offset, stem size and body mass index (BMI) have been discussed [1-3]. In vivo measurements demonstrate that stair climbing is the activity that applies the highest forces including torsion to the shaft of a femoral stem [4]. The anteroposterior load on the femoral head during stair climbing is well over seven times body weight [5]. This force is transmitted to the stem and acts on it with a torque about the femoral shaft that promotes retroversion of the stem. Such torque may endanger the implant's stability [4]. Stem designs with increased rotational resistance have been developed [6], but factors such as the degree of anteversion in which the stem initially implanted may still play an important role in the loading equation. Previous studies have shown a strong increase in the torsional moment with decreasing stem anteversion angles [7]. Furthermore, a correlation between low post-operative stem anteversion and later posterior head migration (PHM) has been reported [1]. Early stem migration as a result of posterior rotation and subsidence is predictive of aseptic loosening [8]. We tested the hypothesis that there is a relationship between the immediate post-operative rotational stem position, measured with three-dimensional CT (3D-CT), and the stem's stability as measured through repeated radiostereometric analysis (RSA) examinations, and later aseptic loosening.

Patients and Methods

Our study group comprised 60 total hip replacements (THRs) performed between 1995 and 1998 in patients with primary osteoarthritis of the hip. This group of patients originated from a cohort used to develop a CT protocol as a precise method of determining anteversion of stems. The data from these patients were also included in an acetabular component evaluation study and then it has gone on to be used to explore the effect of the immediate measured post-operative anteversion position on subsequent observed aseptic loosening. The study selection procedure is outlined in Table I and patient characteristics in Table II. During the ten-year follow-up period, eight patients died and seven discontinued follow-up for medical reasons, none of whom had reported any hip-related complaints. Two patients were excluded, as no relevant RSA results could be obtained owing to inadequate marking by the tantalum beads in the bone. In all, six stems had been revised by ten years, leaving 37 out of 60 hips available for full ten-year analysis.
For clinical evaluation we used the self-administered quality of life questionnaire Short-Form (SF)-36 [9] pre-operatively and at one, two, five and ten years' follow-up.
The study was approved by the Ethics Committee of Lund University, and all patients gave their informed written consent.

Surgical procedure. The patients were placed laterally for operation through a posterolateral approach. The operations were undertaken by eight surgeons in all, comprising both consultants and residents under supervision. Before stem implantation the proximal femur was marked with nine to ten tantalum markers (diameter 0.8 mm), of which three to four were put in the lesser trochanter region and five to six in the greater trochanteric region. The stems were marked by the manufacturer pre-operatively with one tantalum marker (diameter 1.0 mm) at the prosthesis shoulder, one on the collar and one at the tip (Fig. 1). No attempt was made to achieve a particular stem anteversion at surgery, but the surgeons placed the stems in what seemed to be the most suitable position according to their judgement. Prechilled Palacos bone cement with gentamicin (Schering- Plough, Brussels, Belgium) was used and was mixed using the Optivac vacuum-mixing system (Biomet Cementing Technologies, Sjöbo, Sweden). All operations were performed using a distal femoral plug, pulsatile lavage, retrograde cement filling, and cement pressurisation via a proximal femoral seal.

Prosthesis. The ScanHip system with the Optima and Classic II stems (Biomet, Bridgend, United Kingdom) was used. Initially, the Optima stem was to be used in all patients, but during the study its manufacture was discontinued and its design slightly modified to the Classic II, which was considered to be easier to implant. Both stems had a matt surface, a collar and a rounded stem shape. The Optima stem had a straighter shoulder and therefore was broader than the Classic II (Fig. 1). A total of 31 Optima and 29 Classic II stems were used.

Radiostereometric analysis. RSA was carried out using a uniplanar technique with the patient supine [10]. The two Xray sources were fixed, mounted to the ceiling. We used a type-41 calibration cage (Tilly Medical, Lund, Sweden) and the UmRSA computer software version 5.0 (RSA Biomedical, Umeå, Sweden). The reference examination was performed within one week of the operation and served as the datum point for all further examinations. Follow-up examinations were carried out after three and six months, and at one, two, five and ten years, with a time tolerance of 5% to 10% at each interval. We set the cut-off level for exclusion of patients or of specific examinations at a condition number of 150 (an expression for how well the tantalum markers are spread in the segment). For the mean error of rigid body fitting (an expression for marker stability) the cut-off level was set at 0.35 [10].
RSA values were expressed as migration (rotation and translation) about/along the three axes in an orthogonal coordinate system (6° of freedom), and referred to as transverse (x-axis), longitudinal (y-axis) and sagittal (z-axis). We considered distal translation (subsidence) and longitudinal rotation (both in/about the y-axis) as primary effect variables. The precision of the RSA measurements was assessed by 30 double examinations of the patients in the study (Table III). Analogue radiographs taken up to the two-year follow-up were scanned, whereas from the five-year followup onwards direct digital imaging was used, as the hospital had converted to a digital picture archiving and communications system (PACS).

Conventional radiological evaluation. At ten years conventional radiographs were obtained of all the remaining hips. The radiological evaluation included assessment of radiolucent lines (RLLs), including localised endosteal femoral lysis. Osteolysis was defined as cystic lesions with endosteal scalloping not seen on direct post-operative radiographs. The extent and width of any RLL and lysis at the cement– bone interface was measured in Gruen zones 1 to 7, and in zones 8 to 14 when available [11, 12]. The measurements were performed digitally on calibrated computer screen images. The visual definition of radiolucency is sometimes difficult to define. Therefore, in order not to overestimate the phenomenon, we considered a RLL to be present if there was radiolucency > 1 mm wide at the cement–bone interface. Radiological loosening was defined as obvious migration of > 2 mm on plain radiographs combined with osteolysis and RLLs > 50% of the total bone–cement interface. Given the fact that subsidence can obscure otherwise obvious lucent zones around the cement–bone interface, our definition seems to be within safe limits.

CT. CT scans were performed post-operatively to measure stem anteversion using a Toshiba Xpress HS single slice scanner (Toshiba Corp., Tokyo, Japan). Slices were confined to a section through the centre of the femoral head, the middle of the lesser trochanter and the middle of the femoral condyles in the knee. Measurements were performed as described by Murphy et al [13] using a mathematical 3D correction adjusting for the actual positioning of the femur as described by Hermann and Egund [14]. This measurement has been shown to have a precision of 1.6° of anteversion, and the method fulfilled the need for precision as well as being quick to perform. The THRs were graded according to their post-operative anteversion into three groups using a modified Tönnis grade [15] (Table IV).

Statistical analysis. The studied outcomes were translation and rotation of the prostheses in relation to the creation of three groups according to the extent of the post-operative anteversion: < 10°, 10° to 25° and > 25°. The two outcomes were analysed separately using two different statistical models.
Of primary interest was the outcome at ten years after surgery. However, because those who had experienced considerable migration tended to be revised and dropped out of the study before ten years, data for the analysis could not be taken from the ten-year-measurements alone. In order to avoid the bias of including only ‘moderate migrators’, data from the entire follow-up period were used for the analysis.

The relationship between anteversion and translation during the ten years of follow-up was analysed using a random slopes and intercepts model. The model was used in order to account for the correlation structure and heteroscedasticity of the data, which contained repeated measurements on individuals with different migration patterns.
Because the translation rate changed over time, the mean translation development in the model was described using a linear spline with a knot at five years. The approach differs only from the standard regression approach in how it describes the development of migration with time. Instead of attempting to describe the relationship as a straight line, assuming constant migration speed over the entire followup period, a linear spline is made up of several straight lines with different slopes that connect to each other, describing a development scenario where the migration speed is only constant between certain time points, the knots. The knot for the aforementioned model was chosen from visual inspection of the data.
In fitting our statistical model to the data it became evident that there were some prostheses that had migrated rather rapidly compared to the rest of the population, creating outliers in the study population data. When including these in the analyses, the data did not fit the statistical model of normality. Therefore, in order to facilitate analysis, these high-migrators were placed in a separate group, a corresponding indicator variable was added to the model, and their migration was estimated apart from that of the rest of the population. Consequently, in order to estimate the mean translation of the group with the least post-operative anteversion, where the 'high migrators' were present a weighted mean of the 'high' and 'moderate' migrators in the group was used.
Two analyses on the development of translation were performed: one crude and one correcting for prosthesis size, stem type, patient weight, BMI and gender. The estimates produced from the analysis are interpreted as mean differences between anteversion groups at ten years after the operation.
The relationship between progressive posterior stem rotation and post-operative anteversion during the ten-year follow-up was analysed in the same manner as for the translation, with one single exception. The outcome variable was log-transformed before applying the statistical model. This was done because the data were severely skewed and did not fit the statistical model.
The estimates produced from this analysis are to be interpreted as mean ratios between group rotations at ten years after the operation.
We used STATA software version 12 (StataCorp LP, College Station, Texas). All statistical tests of mixed effect model regression parameters were two-sided Wald tests and the standard p-value of < 0.05 was considered statistically significant.

Results

Clinical evaluation. There were no significant differences in clinical evaluation and outcome scores between the three anteversion groups. All patients taken as a single group improved from before surgery to post-operatively, and this persisted throughout the ten-year follow-up (Fig. 2).

Grading system. In ten patients the post-operative anteversion was < 10° (Tönnis grade -3), with a mean of 5° (1° to 9°); 30 patients were in the 10° to 25° group (Tönnis grades -2, 1 and +2) with a mean of 18° (10° to 25°); and 20 had > 25° (Tönnis grade +3) with a mean of 32° (26° to 43°). The mean post-operative anteversion for all stems was 20° (1° to 43°) (Table IV, Fig. 3).

Radiostereometric analysis. The mean migration rates after each follow-up period are summarised in Table V and classified into anteversion groups. There was a strong relationship between the immediate post-operative anteversion and subsequent posterior stem rotation. This could be seen as early as three months and continued to develop during the follow-up period. At ten years all except two stems, both in the > 25° group had rotated into retroversion (anteverted by 0.3° and 0.8°, respectively). At ten years the < 10° group had a significantly higher mean

retroversion of 15.1° (2.5° to 43.1°) compared with 4.7° (1.1° to 17.8°) in the 10° to 25° group and 5.4° (-0.8° to 20.3°) in the > 25° group.
Distal stem migration was in agreement with the findings of rotational migration, with significantly more mean subsidence for the < 10° group at the ten-year follow-up (2.7 mm (0.3 to 10.4) compared with 0.5 mm (-0.3 to 1.7) and 0.4 mm (-0.5 to 1.2), respectively) (Table V).
Inspection of the RSA results can predict aseptic loosening as early as one year post-operatively. In Figure 4 the < 10° group can be seen to consist of two subgroups. Subgroup A contains two stems with consistently very high migratory values throughout the ten-year follow-up period. These two stems had retroversion of 42° and 43° and distal translation of 9.2 mm and 10.4 mm, respectively, at ten years. Subgroup B contains the remaining eight stems in the < 10° group, with a mean retroversion of 8° (2.5° to 17.6°) and a mean distal translation of 1 mm (0.3 to 2.4).
Excluding subgroup A, the stems in the < 10° group had retroverted twice as much as stems in the 10° to 25° group ($p = 0.146$) and 2.5 times more than the > 25° group ($p = 0.068$) (Table VI). Stems in the < 10° group had subsided 0.46 mm more than stems in the 10° to 25° group ($p = 0.086$) and 0.66 mm more than in the > 25° group ($p = 0.020$) (Table VI).
When the two high-migrating stems (subgroup A) were included in our statistical model the < 10° group had rotated into retroversion 3.2 times more than stems in the 10° to 25° group ($p = 0.008$) and 4.1 times more than in the > 25° group ($p = 0.003$) (Table VI). Furthermore, stems in the < 10° group had subsided 3.2 mm more than stems in the 10° to 25° group ($p < 0.001$) and 3.4 mm more than in the > 25° group ($p < 0.001$) (Table VI). The significant differences remain when adjusting for all covariables.
There was no significant difference between the 10° to 25° group and the > 25° group when comparing translation and rotation along the y-axis ($p = 0.327$ and $p = 0.535$, respectively).

Covariables. Adjusting for the covariables weight, BMI, gender, stem size and stem type did not affect the significant differences between the groups. However, the multiple linear mixed-effects model used to correct for these aforementioned covariables showed that the Classic II stem significantly increased the translation (95% confidence interval (CI) 0.007 to 0.159; $p = 0.033$), and small stem size significantly increased both stem translation and retroversion (95% CI 0.051 to 0.232; $p = 0.002$ and 95% CI 0.340 to 0.799; $p = 0.003$, respectively).

Discussion

For these two hip stems initial rotational position of the prosthesis within the femur affected the degree of later posterior rotation and significantly influenced the longevity of the implant. Depending on the design of the prosthesis, we suggest that the rotational position of the stem may be a fundamental factor in determining prosthetic longevity in hip replacement. Implantation with < 10° of anteversion seems deleterious and the subsequent rotational migratory pattern is associated with subsidence and eventual loosening. Measured by RSA this was reflected by a significant difference in retroversion and subsidence between groups, which we originally reported for one year follow-up [16] and clearly this continues up to ten years later. Distal migration before two years may represent normal subsidence and stabilisation within the cement mantle for some stem designs [17]. However, for prostheses that are not designed to subside within the cement mantle continuous migration is likely to be indicative of detrimental results [8,18].
Long-term follow-up has limitations owing to the loss of subjects, which compromises statistical precision. For this reason we have included RSA data from the whole followup period into our statistical model. The inclusion of surgery undertaken by eight different surgeons potentially increased the variation in stem anteversion, better reflecting hip surgery practice in general. The surgeons were not aware of the aim of the study, and so we assume that this spread of anteversion reflects common practice.

Co-variables that might influence the rate of aseptic loosening were taken into account but as they were evenly distributed across the groups they did not influence our findings. However, small stem sizes and different stem types significantly influenced migration in the group as a whole. The ScanHip is rounded in its cross-section in order to obtain an even cement mantle and to avoid stress risers leading to cement fractures. Consequently the rotational stability of the stems was not considered. In retrospect we believe that stems with too-rounded cross-sections are suboptimal with regard to rotational stability [6]. Nevertheless, the biomechanical properties of the stems in this study proved to be a good model for identifying the phenomenon of posterior rotation of the stem.

Bergmann et al [7] measured a marked increase in the torsional moment with decreasing anteversion angles, and Gill et al [1] suggested that stems be placed in ≥ 20° anteversion, based on their observation that there is a correlation between low stem anteversion and posterior head migration. They established that internal rotation, rather than subsidence, is the primary event in loosening. In addition, stems should probably not be anteverted > 30°, as this does not further enhance rotational stability but may contribute to dislocation [1].

There is also a compression-bending force acting on the stem. Increased anteversion, especially in combination with a larger femoral offset, has been shown to raise stresses within the cement mantle [19]. However, this relates only to the bending stresses that mainly load the calcar, but does not take into account the internal rotational torque that is high when loading a hip in flexion [5]. During hip loading in flexion, anteroposterior loading relative to the femoral axis is transformed via the lever arm to the stem as rotational torque (Fig. 5) [1]. We believe that the ability of a stem to withstand compression-bending forces far exceeds its resistance to a rotational torque.

Our results suggest that rotatory forces are important in terms of prosthetic loosening, and therefore axial loading should not be considered in isolation. Posterior rotation of the stem is associated with subsidence within the cement mantle, and thereby appears to be a very important initial mode of stem loosening. Prosthetic anteversion needs to be optimised to withstand the stress of stem torsion caused by the reaction force on a flexed hip. In the future it could be argued that femoral neck anteversion should be measured pre-operatively to find those patients with an increased risk of stem failure because of reduced anteversion relative to the native femoral neck. Our results strongly suggest that rotational positioning of the femoral component during surgery is decisive for the degree of later posterior rotation, subsidence and eventual aseptic loosening. The optimal rotatory position may be sensitive to factors like prosthesis design, stem size and femoral offset, but anteversion of < 10° appears to have a deleterious effect.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article

References:

1. Gill HS, Alfaro-Adrián J, Alfaro-Adrián C, McLardy-Smith P, Murray DW. The effect of anteversion on femoral component stability assessed by radiostereometric analysis. J Arthroplasty 2002;17:997–1005.

2. Olofsson K, Digas G, Kärrholm J. Influence of design variations on early migration of a cemented stem in THA. Clin Orthop Relat Res 2006;448:67–72.

3. Flugsrud GB, Nordsletten L, Espehaug B, Havelin LI, Meyer HE. The effect of middle-age body weight and physical activity on the risk of early revision hip arthroplasty: a cohort study of 1,535 individuals. Acta Orthop 2007;78:99–107.

4. Bergmann G, Deuretzbacher G, Heller M, et al. Hip contact forces and gait patterns from routine activities. J Biomech 2001;34:859–871.

5. Crowninshield RD, Johnston RC, Andrews JG, Brand RA. A biomechanical investigation of the human hip. J Biomech 1978;11:75–85.

6. Kedgley AE, Takaki SE, Lang P, Dunning CE. The effect of cross-sectional stem shape on the torsional stability of cemented implant components. J Biomech Eng 2007;129-3:310–314.

7. Bergmann G, Graichen F, Rohlmann A. Hip joint loading during walking and running, measured in two patients. J Biomech 1993;26:969–990.
8. Kärrholm J, Borssén B, Löwenhielm G, Snorrason F. Does early micromotion of femoral stem prostheses matter? 4-7-year stereoradiographic follow-up of 84 cemented prostheses. J Bone Joint Surg [Br] 1994;76-B:912–917.
9. Sullivan M, Karlsson J, Ware JE Jr. The Swedish SF-36 Health Survey: I: Evaluation of data quality, scaling assumptions, reliability and construct validity across general populations in Sweden. Soc Sci Med 1995;41:1349–1358.
10. Valstar ER, Gill R, Ryd L, et al. Guidelines for standardization of radiostereometry (RSA) of implants. Acta Orthop 2005;76:563–572.
11. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. Clin Orthop Relat Res 1979;141:17–27.
12. Johnston RC, Fitzgerald RH Jr, Harris WH, et al. Clinical and radiographic evaluation of total hip replacement: a standard system of terminology for reporting results. J Bone Joint Surg [Am] 1990;72-A:161–168.
13. Murphy SB, Simon SR, Kijewski PK, Wilkinson RH, Griscom NT. Femoral anteversion. J Bone Joint Surg [Am] 1987;69-A:1169–1176.
14. Hermann KL, Egund N. CT measurement of anteversion in the femoral neck: the influence of femur positioning. Acta Radiol 1997;38:527–532.
15. Tonnis D, Heinecke A. Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. J Bone Joint Surg [Am] 1999;81-A:1747–1770.
16. Hermann KL, Flivik G, Egund N, Ryd L, Jonsson K. Correlation between the rotational position of the femoral stem in cemented total hip replacement and movement around its vertical axis at roentenstereophotogrammetry. Acta Orthop Scand 1998;69:9–10.
17. Stefánsdóttir A, Franzén H, Johnsson R, Ornstein E, Sundberg M. Movement pattern of the Exeter femoral stem; a radiostereometric analysis of 22 primary hip arthroplasties followed for 5 years. Acta Orthop Scand 2004;75:408–414.
18. Hauptfleisch J, Glyn-Jones S, Beard DJ, Gill HS, Murray DW. The premature failure of the Charnley Elite-Plus stem: a confirmation of RSA predictions. J Bone Joint Surg [Br] 2006;88-B:179–183.
19. Kleemann RU, Heller MO, Stoeckle U, Taylor WR, Duda GN. THA loading arising from increased femoral anteversion and offset may lead to critical cement stresses. J Orthop Res 2003;21:767–774.

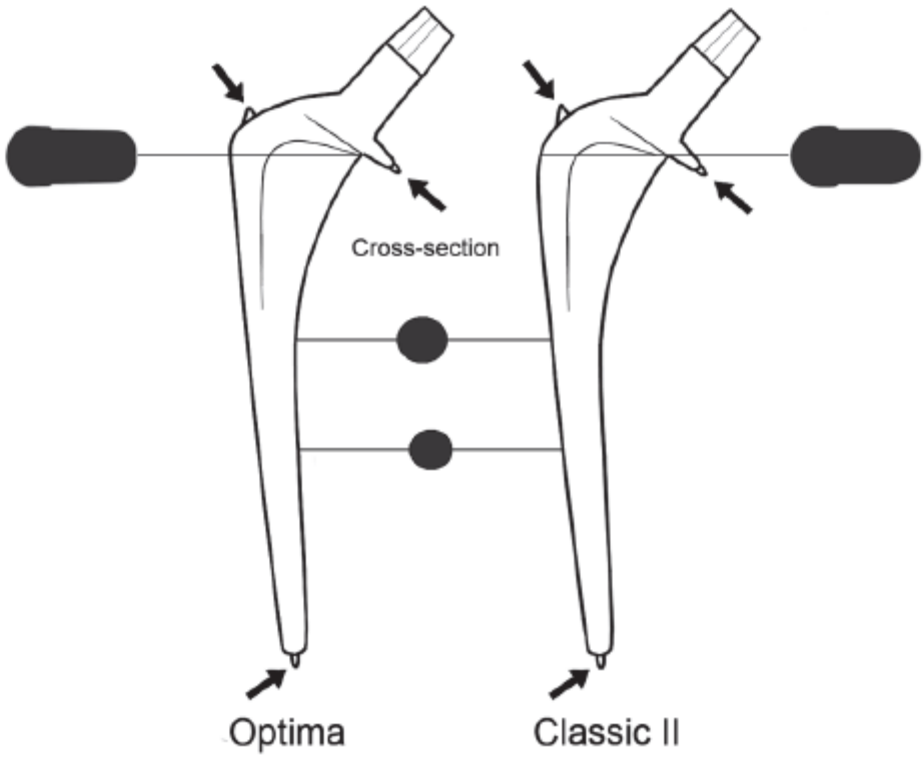


Fig. 1

Diagrams showing the differences between the Optima and Classic II stems. The Optima stem has a straight shoulder and is therefore broader than the Classic II stem, which has a rounder shoulder for easier placement. Both stems are rounded in cross-section. The manufacturer supplied these stems with titanium towers, each with a tantalum marker attached to its tip at the prosthesis shoulder, collar and tip (arrows).

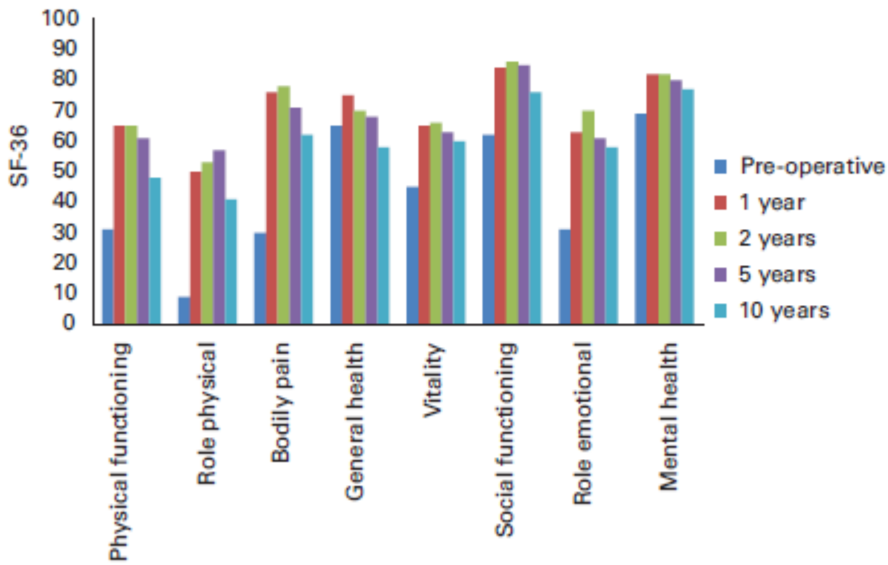
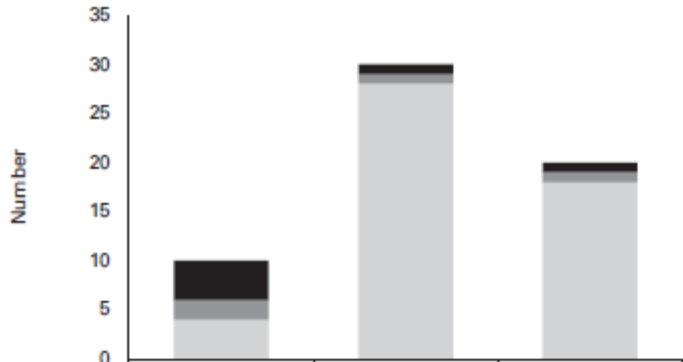


Fig. 2

Bar chart showing the mean Short-Form (SF)-36 subscores for thewhole study group.



	< 10°	10° to 25°	> 25°
Revised	4	1	1
Radiologically loose	2	1	1
Stable at last follow-up	4	28	18

Fig. 3

Chart showing the incidences of aseptic loosening in the low (< 10°), normal (10° to 25°) and high (> 25°) anteversion groups. At ten years four stems were considered radiologically loose, two in group < 10°, one in group 10° to 25° and one in group > 25°. These patients were either too unfit to cope with revision surgery or did not experience sufficiently debilitating symptoms.

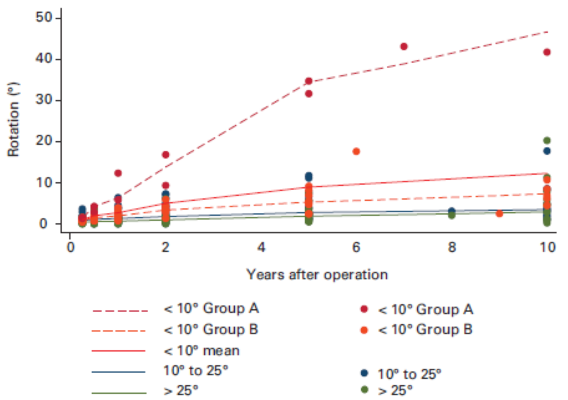


Fig. 4a

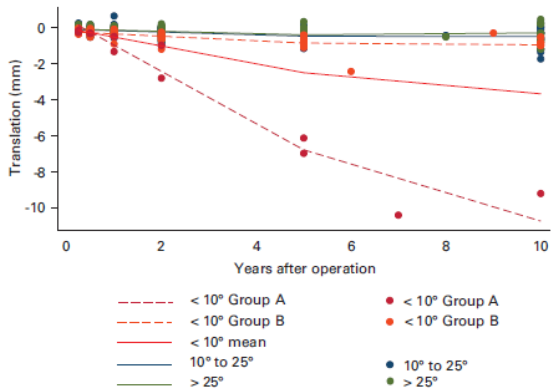


Fig. 4b

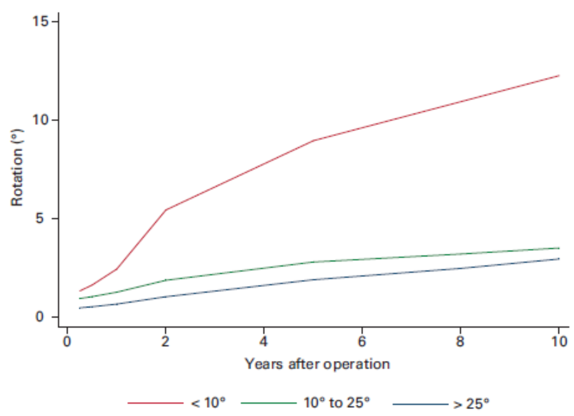


Fig. 4c

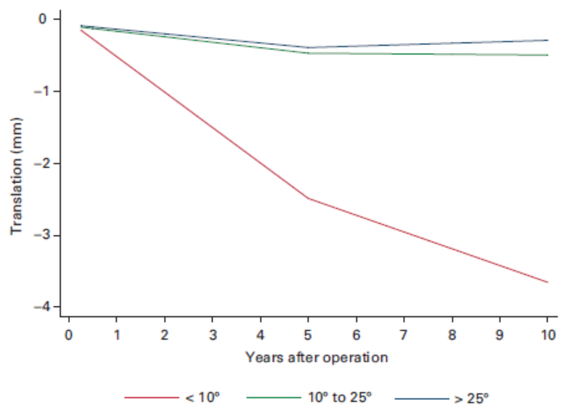


Fig. 4d

Figure 4a – graph showing the values of stem retroversion by anteversion group (< 10°, low; 10° to 25°, normal; > 25°, high) across the ten-year followup. The low anteversion group is divided into subgroup A (two stems with consistently high results) and B (the remaining eight stems). Figure 4b – graph showing the stem subsidence by anteversion group (including the subgroups A and B of the < 10° group). Figures 4c and 4d – graphs showing the mean retroversion (c) and subsidence (d) of the stems in all groups without subgroup analysis. All graphs are corrected for dropouts, including radiostereometric analysis pre-revision and loss to follow-up.

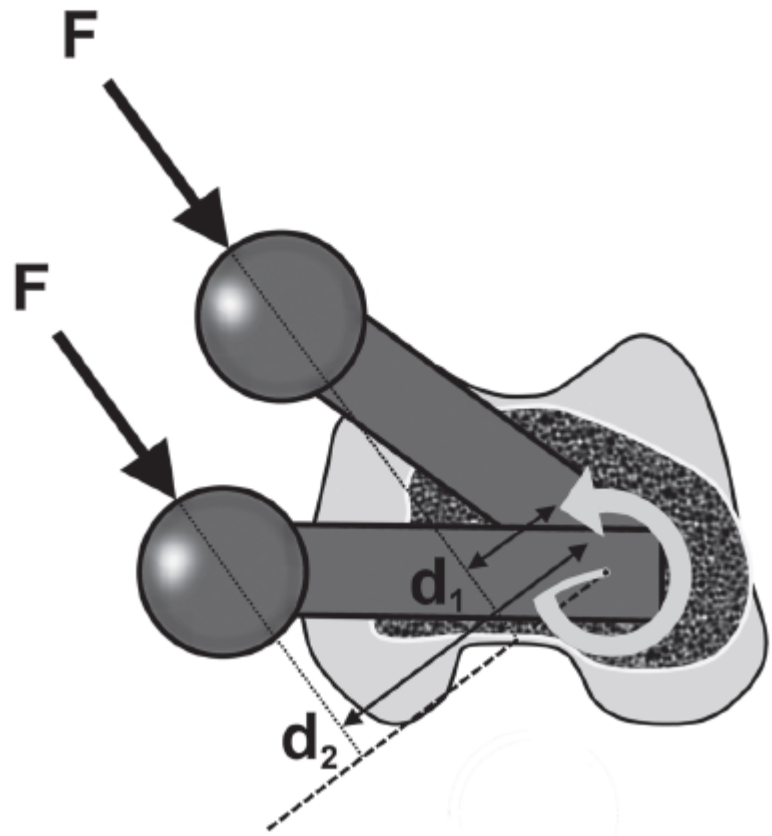


Fig. 5

Diagram of a hip prosthesis from above at two different levels (dark grey, minor trochanter level; light grey, epicondylar level), showing the mechanism of internal rotational torque. Torque (circular arrow) = Hip joint reaction force (F) × Lever arm (d). The hip joint reaction force (F) is transformed via the lever arm to the stem as rotational torque. A reduced anteversion angle in a hip loaded in flexion will increase the internally rotating torque because of the relative longer lever arm (d_2). A shorter lever arm (d_1) results in less torque.

Table I. Selection procedure. Patients who understood the conditions of the study and were willing to participate for the duration of the prescribed follow-up, and patients who were capable of, and had given their informed consent to, participation in the study were asked to enrol

Inclusion criteria	Exclusion criteria
Osteoarthritis of the hip	Rheumatoid arthritis, severe dysplasia or protrusion
Male and non-pregnant female	Malignant disease
Aged 50 to 85 years at time of study	Major surgery or fracture in the hip to be operated
Charnley groups A and B	Ongoing corticosteroid (oral) or immunosuppressive medication

Table II. Demographic data (BMI, body mass index)

Characteristic	
Total number (n)	60
Gender (n, %)	
Male	28 (*47*)
Female	32 (*53*)
Laterality (n, %)	
Right	28 (*47*)
Left	32 (*53*)
Mean age at operation (yrs) (range)	67 (51 to 82)
Mean BMI at operation (kg/m^2) (range)	27 (20 to 36)

Table III. Precision of radiostereometric analysis for assessment of stem migration

Axis	Translation (mm)*	Rotation (°)*
Transverse (x)	0.30	0.69
Longitudinal (y)	0.33	0.44
Sagittal (z)	0.46	0.41

* precision of measurements based on 30 double investigations. Given number represents the smallest migration value that is considered significant and is based on 2.7 standard deviations of the error obtained. This, hence, represents the 99% confidence limit

Table IV. Modification of the Tönnis grading system[15]

	Tönnis system		Our modification	
Grade	Anteversion (°)	Description	Anteversion (°)	Description
Grade -3	< 10°	Severely decreased	< 10°	Low
Grade -2	10° to 14°	Moderately decreased		
Grade 1	15° to 20°	Assumed normal	10° to 25°	Normal
Grade +2	21° to 25°	Moderately increased		
Grade +3	> 25°	Severely increased	> 25°	High

Table V. Results of radiostereometric analysis

	Mean migration (median)					
	3 months	**6 months**	**1 year**	**2 years**	**5 years**	**10 years**
Rotation (°)						
x-axis						
< 10°	0.15 (0.09)	0.21 (0.18)	0.23 (0.15)	0.48 (0.38)	1.39 (0.89)	1.38 (0.64)
10° to 25°	-0.12 (-0.07)	-0.07 (-0.06)	-0.11 (-0.04)	0.03 (0.01)	0.45 (0.44)	-0.19 (-0.13)
> 25°	-0.02 (0.03)	0.08 (0.07)	0.07 (0.10)	0.18 (0.22)	0.64 (0.63)	-0.19 (-0.09)
y-axis						
< 10°	1.08 (1.11)	2.04 (1.83)	3.64 (2.54)	5.53 (3.87)	11.11 (6.24)	15.11 (8.87)
10° to 25°	1.00 (0.77)	1.24 (1.19)	1.98 (1.50)	2.51 (1.73)	3.84 (2.45)	4.67 (3.36)
> 25°	0.28 (0.30)	0.73 (0.65)	0.73 (0.73)	1.24 (1.09)	2.34 (2.33)	5.38 (4.63)
z-axis						
< 10°	-0.13 (-0.12)	-0.20 (-0.15)	-0.39 (-0.28)	-0.64 (-0.55)	-1.20 (-0.79)	-1.97 (-1.30)
10° to 25°	-0.02 (-0.04)	-0.11 (-0.12)	-0.23 (-0.19)	-0.24 (-0.21)	-0.39 (-0.31)	-0.69 (-0.39)
> 25°	-0.06 (-0.05)	-0.07 (-0.06)	-0.10 (-0.11)	-0.10 (-0.18)	-0.18 (-0.31)	-0.23 (-0.37)
Translation (mm)						
x-axis						
< 10°	0.04 (0.03)	0.06 (0.06)	0.17 (0.18)	0.25 (0.13)	0.00 (0.03)	-0.04 (0.07)
10° to 25°	0.04 (0.05)	0.07 (0.05)	0.10 (0.07)	0.15 (0.07)	0.17 (0.13)	0.29 (0.17)
> 25°	0.00 (0.02)	0.04 (0.01)	0.80 (0.05)	0.18 (0.12)	0.19 (0.19)	0.56 (0.43)
y-axis						
< 10°	-0.18 (-0.17)	-0.26 (-0.27)	-0.48 (-0.43)	-0.84 (-0.59)	-1.89 (-0.81)	-2.71 (-0.91)
10° to 25°	-0.06 (-0.06)	-0.14 (-0.11)	-0.16 (-0.16)	-0.32 (-0.26)	-0.45 (-0.42)	-0.51 (-0.36)
> 25°	-0.05 (0.02)	-0.13 (-0.09)	-0.12 (-0.11)	-0.25 (-0.25)	-0.38 (-0.43)	-0.39 (-0.47)
z-axis						
< 10°	-0.20 (-0.20)	-0.38 (-0.23)	-0.94 (-0.49)	-1.50 (-0.77)	-3.28 (-1.95)	-3.24 (-2.04)
10° to 25°	-0.18 (-0.18)	-0.28 (-0.21)	-0.47 (-0.31)	-0.74 (-0.39)	-1.43 (-1.21)	-1.20 (-1.00)
> 25°	-0.04 (-0.04)	-0.14 (-0.18)	-0.13 (-0.11)	-0.43 (-0.25)	-1.16 (-1.08)	-1.61 (-0.88)

Table VI. Posterior rotation around the y-axis at ten years (Low (< 10°); Normal (10° to 25°); High (> 25°); CI, Confidence interval)

	Posterior stem rotation (y-axis)			**Distal translation (y-axis)**	
	Ratio* (95% CI)	**p-value**		**Difference† (95% CI)**	**p-value**
High/Normal	0.80 (0.39 to 1.64)	0.535	Normal – High	0.20 (-0.20 to 0.61)	0.327
Low‡/Normal	2.00 (0.79 to 5.03)	0.146	Normal – Low‡	-0.46 (-0.98 to 0.07)	0.086
Low‡/High	2.50 (0.94 to 6.70)	0.068	High – Low‡	-0.66 (-1.22 to -0.10)	0.020
High/Normal	0.80 (0.39 to 1.64)	0.535	Normal – High	0.20 (-0.20 to 0.61)	0.327
Low§/Normal	3.23 (1.35 to 7.72)	0.008	Normal – Low§	-3.16 (-3.65 to -2.68)	< 0.001
Low§/High	4.06 (1.60 to 10.3)	0.003	High – Low§	-3.37 (-2.84 to -3.89)	< 0.001

* estimates produced from this analysis are to be interpreted as average ratios between groups
† estimates produced from the analysis are to be interpreted as mean differences between groups
‡ not including stems with high migration
§ including stems with high migration