The validity of a novel radiological method for measuring femoral stem version on anteroposterior radiographs of the hip after total hip arthroplasty

Femoral stem version has a major influence on impingement and early post-operative stability after total hip arthroplasty (THA).

The main objective of this study was to evaluate the validity of a novel radiological method for measuring stem version. Anteroposterior (AP) radiographs and three-dimensional CT scans were obtained for 115 patients (female/male 63/72, mean age 62.5 years (50 to 75)) who had undergone minimally invasive, cementless THA. Stem version was calculated from the AP hip radiograph by rotation-based change in the projected prosthetic neck–shaft (NSA*) angle using the mathematical formula $ST = \text{arccos} \left(\frac{\tan(\text{NSA}^*)}{\tan 135}\right)$. We used two independent observers who repeated the analysis after a six-week interval. Radiological measurements were compared with 3D-CT measurements by an independent, blinded external institute.

We found a mean difference of 1.2° (SD 6.2) between radiological and 3D-CT measurements of stem version. The correlation between the mean radiological and 3D-CT stem torsion was $r = 0.88$ ($p < 0.001$). The intra- (intraclass correlation coefficient ≥ 0.94) and inter-observer agreement (mean concordance correlation coefficient = 0.87) for the radiological measurements were excellent.

We found that femoral tilt was associated with the mean radiological measurement error ($r = 0.22$, $p = 0.02$).

The projected neck–shaft angle is a reliable method for measuring stem version on AP radiographs of the hip after a THA. However, a highly standardised radiological technique is required for its precise measurement.

Cite this article: Bone Joint J 2015; 97-B:306–11.
Patients and Methods

During the course of a registered, prospective controlled trial (DRKS00000739, German Clinical Trials Register), hip radiographs in two planes (AP and axial) and 3D-CT scans were obtained for patients who had undergone THA. The investigation was approved by the local ethics commission (no.10-121-0263). All procedures were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000. This study is a secondary analysis of a larger project. The primary outcome of this study was to assess whether the ROM of the prosthetic joint could be improved by computer-assisted functional optimisation of the position and containment of the acetabular component.

A consecutive series of 783 patients with arthritis of the hip was screened. The inclusion criteria were; age between 50 and 75 years; an American Society of Anesthesiologists (ASA) score ≤ 3; unilateral arthritis of the hip (up to Kellgren grade 2 on the opposite side); no previous hip surgery; no hip dysplasia; and no history of trauma. A total of 597 patients did not meet the inclusion criteria, 27 declined to participate in the study and another 19 could not be included for other reasons, e.g. the operation was cancelled, or the patient had raised inflammatory markers on blood testing the day before surgery. The first five navigated THAs (primary study outcome) were regarded as the learning curve and therefore no CT data were available. Finally, a consecutive series of 135 patients were enrolled in this single-centre study, 20 of whom had to be withdrawn. Four withdrew their informed consent and refused further participation in the study, as well as use of their data. In one patient a different stem type was used owing to the specific anatomy of the individual. In seven patients, no post-operative CT scans were available, and in eight there was an obvious rotational error on the post-operative radiographs. In total, the records of 115 THAs were included for final analysis. Characteristics of the study group are shown in Table I.

After obtaining written consent from the patients, THA was undertaken by one of four experienced orthopaedic surgeons (TR, JG) from the Department of Orthopaedic Surgery, Regensburg University Medical Centre. All operations were carried out with the patient in a lateral decubitus position (primary study outcome) were regarded as the learning curve and therefore no CT data were available. Finally, a consecutive series of 135 patients were enrolled in this single-centre study, 20 of whom had to be withdrawn. Four withdrew their informed consent and refused further participation in the study, as well as use of their data. In one patient a different stem type was used owing to the specific anatomy of the individual. In seven patients, no post-operative CT scans were available, and in eight there was an obvious rotational error on the post-operative radiographs. In total, the records of 115 THAs were included for final analysis. Characteristics of the study group are shown in Table I.

After obtaining written consent from the patients, THA was undertaken by one of four experienced orthopaedic surgeons (TR, JG) from the Department of Orthopaedic Surgery, Regensburg University Medical Centre. All operations were carried out with the patient in a lateral decubitus position using a minimal-incision anterolateral surgical approach to the hip joint which followed the intermuscular and interneural tissue planes between tensor fascia lata and gluteus medius. The same press-fit components (Pinnacle; DePuy, Warsaw, Indiana) and same cement-free hydroxyapatite-coated stems (Coral; DePuy) were used in all patients. The tribological pairing consisted of neutral polyethylene liners and modular metal heads with a diameter of 32 mm.

Six weeks post-operatively, full weight-bearing standing radiographs of the operated hip were obtained in the AP and axial planes (MULITX TOP ACSS, Siemens, Erlangen, Germany). The radiographer made sure that the pelvis was set parallel to the plane of the film without rotation or flexion of the hip joint and the leg placed in a neutral position the patella pointing forward disregarding the foot progression angle in the event of a tibial torsion. All radiographs were to be taken under these standardised conditions (focus–film distance 115 cm, 75 kV, automatic exposure). However, in eight patients correct placement was not achieved and these radiographs were excluded. At the same visit a CT scan was obtained from the pelvis down to the femoral condyles (Somatom Sensation 16; Siemens, Erlangen, Germany).

For the assessment of radiological SV we used digital planning software (mediCAD; Hectec GmbH, Landshut, Germany). First we measured the projected neck–shaft angle of the femoral component on the AP radiographs. For exact determination of the axis of the stem, circles were interposed digitally in the stem with their margins touching the edges of the stem. A line passing through the centres of the circles formed the stem axis. Similarly, the neck axis was defined by a line passing through the centre of the head and the centres of the circles along the neck. The angle between the axes of the neck and stem was regarded as the neck–shaft angle (Fig. 1). Both anteversion and retroversion around the axis of the femur cause the projected neck–shaft angle to appear increased. The true neck–shaft angle of the stem (NSAT) is a known to be 135°. This means the higher the version of the stem the higher the projection-based increase of the NSAT. Using a newly developed mathematical formula, SV was calculated by rotation-dependent projection of the NSAT. Because the true NSAT of the implant is known, the extent of SV could be calculated by measuring the projected NSAT angle. The relationship between SV and the projected angles is explained by the cosine function. Therefore, the calculation of SV based on the NSAT is possible according to the following formula:

\[ SV = \text{arccos} \left[ \frac{\tan (\text{NSAT})}{\text{tan} (\text{NSAT})} \right] \]

where arccos is the inverse of the cosine. The correlation of radian and angle measurement is described by \( \pi = 180° \). The axial view differentiated between general anteversion and retroversion.
of the femoral stem. All radiological measurements were performed by two independent observers, who repeated the measurements after a six-week interval. The observers were blinded to each other’s results as well as to the 3D-CT values of SV. By contrast, 3D-CT assessment of prosthetic SV was obtained by an independent, blinded external institute (MeVis Medical Solutions, Bremen, Germany), as described by Sendtner et al. Briefly, first the condylar axis of the femur is calculated and the mechanical axis of the femur defined by the centre of the caudal contact points of the femoral condyles and the centre of the femoral head. A reference point on the prosthesis is defined so that the vector towards the centre of the femoral head represents the neck of the prosthesis. The normal vector of the plane created from this reference point and both points of the mechanical axis are projected onto a plane orthogonal to the mechanical axis. We calculated the angle between this vector and the orthogonal projected condylar axis and subtracted 90°, thereby defining the degree of femoral stem torsion (Fig. 2). Femoral tilt was calculated using 3D-CT as the deviation between the femoral stem and the mechanical axis in the sagittal projection.

**Statistical analysis.** Differences between the radiological and 3D-CT assessments of femoral stem version were analysed descriptively: means were reported with standard deviations (SD) and 95% confidence intervals (CI). To account for repeated measurements, the latter statistics have been computed by mixed model analysis using a diagonal working correlation matrix. Corresponding Bland–Altman plots are presented to illustrate the comparison between the methods. Intra-observer reliability was tested using intraclass correlation coefficients (ICC) for each observer: interobserver reliability was assessed using the mean concordance correlation coefficient (CCC) of all assessments, paired across observers. The correlation between mean radiological and 3D-CT measurements was evaluated by Spearman’s correlation coefficient (r). Similarly, the correlation between the mean absolute radiological measurement error and BMI, femoral tilt and stem size was analysed using Spearman’s correlation coefficient (r). Non-parametric tests (Mann–Whitney U test) were used to analyse the association between the mean absolute radiological measurement error and stem geometry or treatment side. Correlation was characterised as poor (0.00 to 0.20); fair (0.21 to 0.40); moderate (0.41 to 0.60); good (0.61 to 0.80) or excellent (0.81 to 1.00). Statistical analyses were performed using IBM-SPSS Statistics 21 (SPSS Inc., Chicago, Illinois) and the statistical software package R (The R Foundation for Statistical Computing, Vienna, Austria). A p-value < 0.05 was considered statistically significant.

**Results**

The mean difference between the radiological and the 3D-CT-based measurement of femoral SV was 1.2° (SD 6.2°, -12.3° to 13.7°). The individual assessments of all four radiological measurements of SV as well as 3D-CT are shown in Table II. The correlation between the mean radiological and 3D-CT analyses of femoral ST was r = 0.88 (p < 0.001). The mean difference between radiological and 3D-CT measurements of SV can be expected to be between 0.3° and 2.2° according to the 95% confidence interval.
been shown to be related to the position of the femoral
THA. This is of significance as early dislocation has

Discussion

A wide range of femoral stem version has been reported after
THA. This is of significance as early dislocation has
been shown to be related to the position of the femoral
component. In this study we found a range of post-
operative cementless femoral stem version between -18.9°
and 37.7°, which is consistent with the current literature.

Sendtner et al report a series of 60 patients undergoing
THA SV ranging from -19° retroversion to 33° anteverision.
Wines and McNicol report cementless stem anteverision
between -12° and 52° in 111 primary THAs. Dorr et al found a range of cementless stem version between -8.6°
and 27.1° in a series of 109 patients. Owing to the impact of femoral version, surgeons need a practicable and reliable
measurement of SV. So far, CT has been the reference stan-
dard for post-operative assessment of SV, but this requires
additional exposure to radiation and costs more. We found
this novel radiological method for the evaluation of SV to
be both valid and reliable. Only femoral tilt correlated, and
then only slightly, with the measurement inaccuracies of SV.

Femoral tilt is the angular difference between the long axis
of the femoral stem and the mechanical axis on a sagittal
radiograph. This is based on the principle that the stem of
the prosthesis follows the natural anterior bow of the prox-
imal femur.16

There are several limitations to this study. First, the radi-
ological formula is unable to differentiate between antever-
sion and retroversion. Therefore, a second axial radiograph
is needed to distinguish between the two. Although we did
not experience any problems with this procedure, a 5°devi-
ation between anteverision and retroversion of the stem may
be difficult to see in the axial plane. Second, the described
technique is based on the projection-induced change in the
known NSA: this implies knowledge of the true NSA of
the prosthetic stem. Third, the mathematical model is only
defined for angles exceeding the known NSA. However, in
17 of the 460 individual radiological measurements we
obtained values below the known NSA of 135°. These values
ranged from 133.9° to 134.9°. In order not to conceal
potential radiological outliers, these values were regarded
as the lowest possible NSA representing 0° SV. Fourth, this method calculates the general rotation of the
neck towards the plane of the film and therefore reflects a
combination of neck torsion and leg rotation. This means
that any external or internal rotation of the leg will result in
misinterpretation of the degree of stem torsion. Another
factor is the influence of hip extension and flexion on the
projected NSA angle. Consequently, a rigorously stand-
ardised radiological technique is needed to guarantee exact
positioning of the patient with the minimum of projection
ersors. Furthermore, the observer has to check the quality
of the radiograph carefully before measuring SV. Our
measurements were obtained under optimised conditions following a strict protocol. Despite this, in eight cases the radiological image was inadequate, which suggests a potential limitation to the method in a clinical setting.

In this study, 3D-CT analysis was used as a reference method because of its high accuracy and reliability in the precise radiological measurement of stem version in THA. However, its applicability to routine post-operative follow-up examinations is limited because of the significant radiation exposure, cost and artefacts created by the implants.

In children with cerebral palsy, complex automated 3D morphological models have been described which enable SV to be measured from a single AP image with a mean difference of 3.38°. Rippstein developed a special radiological imaging method for measuring femoral anteversion in children. Budin and Chandler proposed AP radiographs of the hip in a sitting position with 90° flexion of both hip and knee. However, the applicability of this technique was limited to children aged up to six years because the image quality became degraded in older children.

So far, there is only one method of measuring femoral version after cementless THA in adults. In short, this modified ‘Budin view’ uses a posteroanterior radiograph of the hip in 90° flexion and 30° abduction and with 90° flexion of the knee. Lee et al. found a high correlation between the radiological and CT measurements (r = 0.877, p < 0.001) with excellent intra-(0.944) and inter-observer reliability (0.934). The mean difference between CT and radiological assessment of ST was reported to be 1.01°.

We were able to define stem version with only a mean difference of 1.2° from 3D-CT with no need for any additional imaging except routine post-operative AP radiographs. All results showed excellent intra- (ICC ≥0.94) and inter-observer (CCC = 0.87) agreement. In all, 91% of the radiological measurements were within 10° of those derived from 3D-CT. Had we changed the benchmark to 5° or 5°, 85% and 74% of radiological measurements, respectively, would have been within these limits. When we looked into possible reasons for the radiological misinterpretation of ST, only femoral tilt correlated slightly (r = 0.22; p = 0.02) with the radiological measurement error. We measured femoral tilt in the 3D-CT-based femoral coordinate system, which might explain the only slight correlation with the radiological measurement error of ST. Neither BMI, side of treatment nor stem geometry or size were associated with radiological deviation of SV from 3D-CT. Overall, this mathematical approach to measuring SV to be measured from a single AP image with a mean difference of 1.2° from 3D-CT with no need for any additional imaging except routine post-operative AP radiographs. All results showed excellent intra- (ICC ≥0.94) and inter-observer (CCC = 0.87) agreement. In all, 91% of the radiological measurements were within 10° of those derived from 3D-CT. Had we changed the benchmark to 5° or 5°, 85% and 74% of radiological measurements, respectively, would have been within these limits. When we looked into possible reasons for the radiological misinterpretation of ST, only femoral tilt correlated slightly (r = 0.22; p = 0.02) with the radiological measurement error. We measured femoral tilt in the 3D-CT-based femoral coordinate system, which might explain the only slight correlation with the radiological measurement error of ST. Neither BMI, side of treatment nor stem geometry or size were associated with radiological deviation of SV from 3D-CT. Overall, this mathematical approach to measuring SV on AP radiographs of the hips allows a simple and practicable evaluation of post-operative femoral stem version. CT remains the reference standard when a range of accuracy of ± 3° is required.

Supplementary material

Figures illustrating stem version and its projection, as well as mathematical approach to the calculation of stem version using the projection-based change of the known neck–shaft angle are available with this article online at www.bjj.boneandjoint.org.uk

Author contributions

M. Weber: Writing the paper, Organisation, Data analysis.
F. Lechner: Scientific background, Organisation.
E. von Kunow: Data analysis, Measurements.
F. Vollner: Data collection.
A. Keshmiri: Data collection.
A. Hafpelmeyer: Statistical analysis.
J. Grifka: Senior surgeon, Supervision of the project.
T. Renkawitz: Senior surgeon, Supervision of the project, Writing the paper.

We thank M. Woerner and Dr E. Sendtner for performing the operations together with the co-authors. This project was funded by the German Federal Ministry of Education and Research (BMBF) under Project Number 01EZ0915.

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.

This article was primarily edited by G. Scott and first proof edited by A. C. Ross.

References


THE BONE & JOINT JOURNAL


