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Femoral Subsidence Assessment After Hip Replacement
An Experimental Study

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Abstract

Background: In an experimental set up information is to be gained on the error of measurement for subsidence assessment of the stem after hip replacement.

Methods: Subsidence was measured with a pencil and ruler for four different reference lines and with the computerized EBRA-FCA method. Hip flexion, rotation and abduction were simulated in a standardized way. In a second experimental set up, subsidence was simulated in defined steps.

Results: In the tilt study, the maximum error of measurement was 7 mm with standard methods and 1.7 mm with the EBRA-FCA method. In the subsidence study, there was a maximum error of measurement of 1.9 mm with the standard methods. With EBRA-FCA, the maximum error of measurement was 0.2 mm when taking all radiographs into account.

Conclusions: The main error of subsidence measurement is caused by tilt of the femur for standard methods and partly can be reduced by EBRA-FCA. EBRA-FCA is more reliable than standard methods but might underestimate the actual subsidence in a clinical situation.

Introduction

The assessment of prosthetic migration and subsidence after hip replacement is an established means of quality control. Early and continuous motion of the implant against the surrounding bone can predict a higher percentage of late aseptic loosening (1, 2).

In cup analysis it was shown that pelvic tilt is the main source for errors of measurement with standard methods (3, 4) which partly can be detected and corrected with the computerized EBRA method (5).

For subsidence measurements of femoral components various prominent bone markers were proposed. Choosing reference lines close to the implant, correcting radiographic magnification and using highly standardized radiographs may improve measurement accuracy (6–8). Whether the implantation of metal markers can improve the accuracy of standard measurements is discussed controversially (3, 9, 10).

As for the cup, the main source of error of measurement seems to be eventual tilt and rotation of the femur. The EBRA-FCA method is thought to detect projection differences, thus reducing the error of measurement (6, 9).

In an experimental study we tried to gain further information on eventual errors of measurement. The effect of tilt of the femur on the measurements was tested for

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EBRA-FCA and standard measurements. Furthermore, subsidence of the implant was simulated to get information about the measurement accuracy in case of implant loosening.

Material and Methods

Methods of measurement

Subsidence was measured with pencil and ruler methods in four different ways (3). A line was drawn parallel to the longitudinal axis of the femur through the centre of the medullar canal. A perpendicular line was drawn to the femoral axis, being a tangent to the tip of the major trochanter. Another perpendicular line was drawn through the most prominent point of the lesser trochanter. The centre of the femoral head was marked with a template of concentric circles. The tip of the prosthetic shoulder was defined as the most prominent lateral edge of the implant. The distance of the head-centre to the major and lesser trochanter (H.-major, H.-lesser) and of the tip of the prosthetic shoulder to the major and lesser trochanter (S.-major, S.-lesser) were measured. Variations in the distance as compared to the neutral position were seen as subsidence (Figure 1). Radiological enlargement was calculated from the measured head-size in relation to the real head-size of 32 mm. All radiographs were measured in random order by one person in the same way.

The EBRA-FCA measurements were made as described by Biedermann et al. (6). The radiographs were digitised and the reference lines drawn on the screen. Extreme projection differences were to be detected and excluded from analysis. Only radiographs with similar projections were to be used by the software for subsidence assessment.

Each radiograph was marked with a different date of examination, simulating one radiographic examination per day and permitting a change of the order of the radiographs by changing the dates. The data were presented as time-subsidence graphs and plotted in excel files for statistical analysis.

1. Tilt study

An uncemented staight femoral component (BiContact®, Aesculap®, Germany) was implanted in a human plastic right (Synbones®) femur and in a left femur (Sawbones®), respectively.

The bones used differed in size and shape and the prosthetic femoral components differed in the position of implantation. A polyethylene cup was fixed in 40° inclination and slight anteversion in the testing machine, simulating the geometry of a standard hip replacement and modular 32 mm metal heads were used. The hip could be flexed and extended, abducted and adducted, internally and externally rotated and fixed in each desired position (Figure 2). Starting from a zero position, consecutive movements were made in two degree steps up to 16 of degrees flexion and 4 of degrees extension, 10 degrees of abduction and 8 degrees of adduction, 10

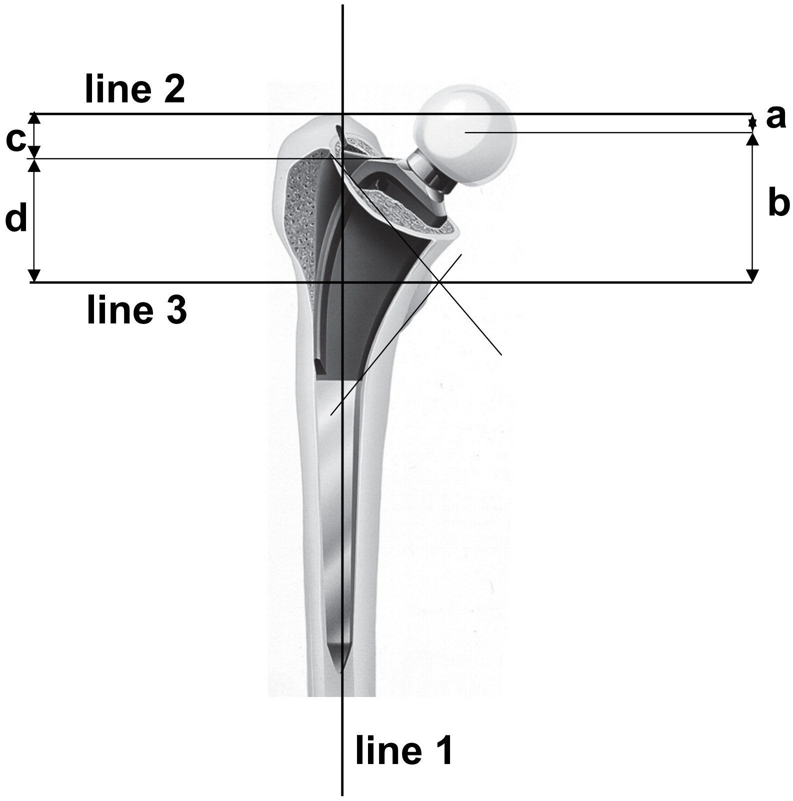

Figure 1. Standard measurements of subsidence. The femoral axis is marked (line 1) and a perpendicular line drawn tangential to the tip of the major trochanter (line 2) and through the most prominent point of the lesser trochanter (line 3). The distances from the head centre (a, b) and from the tip of the prosthetic shoulder (c, d) to line 2 and 3, respectively, are measured. Distance a is the head – major trochanter distance (H.-major), b the head – lesser trochanter distance (H.-lesser), c the shoulder – major trochanter distance (S.-major) and d the shoulder – lesser trochanter distance (S.-lesser).

degrees of internal and external rotation and controlled with a goniometer. Furthermore, combined movements of flexion and rotation were made up to 8 degrees of flexion and 6 degrees of external rotation. For each position a standardized radiograph of the hip was taken, centred in the middle of the femoral component. A left and a right hip were examined, 36 radiographs were produced for each side.

The radiographs were sorted in subgroups of linear increasing flexion, abduction and internal rotation to detect eventual systematic errors due to consecutive tilt. In order to simulate a more clinical situation, subgroups of five radiographs were selected randomly out of the data-pool and measured with all methods.

2. Subsidence study

The same type of femoral component was fixed with a custom-made device in a right plastic femur. It could be moved in the femoral canal along the femoral

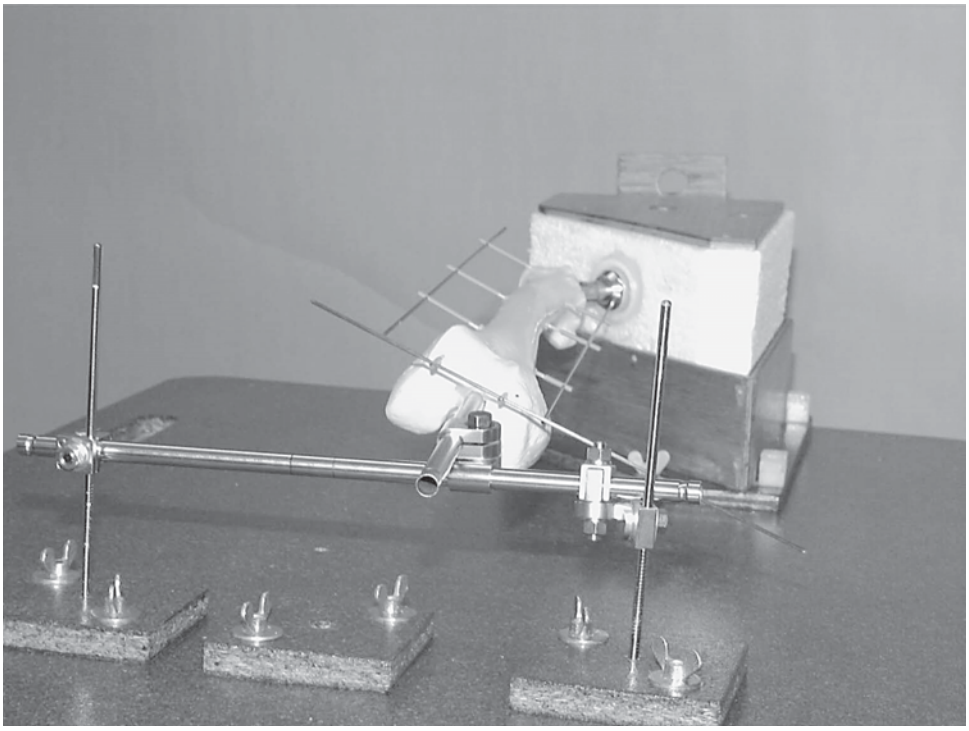

Figure 2. Simulation of flexion, abduction and rotation. The angles of the guide wires in relation to the board were measured with a goniometer. Each position was fixed with screws when taking a radiograph.

axis by turning a handlebar, simulating subsidence. The amount of subsidence was measured with a slide calliper (Figure 3). The implant was moved in 0.2 mm steps up to a maximum subsidence of 7.0 mm. For each step a standard radiograph of the hip was taken with the femur in the same neutral position. All 36 radiographs were measured with all methods.

Data was collected on a PC and processed with MS Excel. In the tilt study, the absolute differences of the measurements of the radiograph in neutral position and in the subsidence study, the absolute difference of actual subsidence were seen as errors of measurement. Mean, median and standard deviation of those errors of measurement were calculated.

Results

1. Tilt study

In the right femur, the distance of the head centre to the tip of the major trochanter was 8.1 mm in neutral position. The head size was 39.5 mm, meaning an enlargement of 1.2.

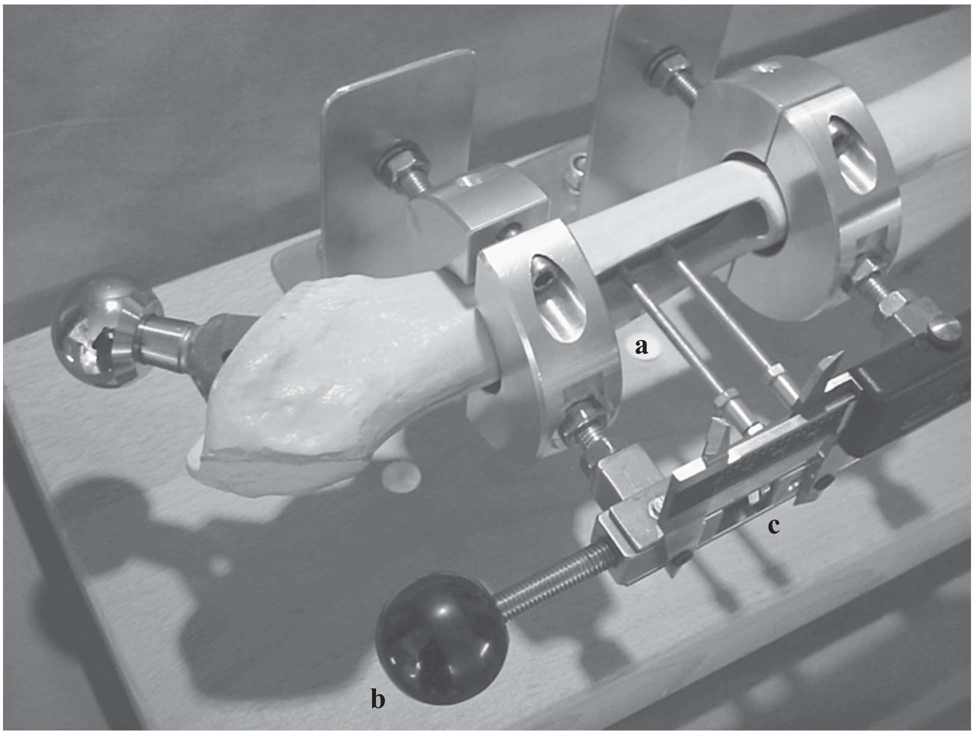

Figure 3. The femoral component was fixed with two screws (a) on the measuring frame and could be moved along the axis of the femur. Subsidence was simulated by turning the handlebar (b) and measured with the slide calliper (c).

When looking at the radiographs in 0 degrees and 16 degrees of flexion, the measured length of the stem on the radiographs differed by 1.7 mm.

The most obvious projection differences were found in the shape of the proximal hole and in the projection of the shoulder of the implant.

With the standard measurements the maximum error was 7.5 (SD 2.35) mm and was found for measurements of the head centre in relation to the lesser trochanter (Table 1). The main error was found for movements in extension-flexion (mean 4.0 mm, SD 2.90), followed by abduction-adduction (mean 1.0 mm, SD 0.95) and external-internal rotation (mean 0.7 mm, SD 0.42). For the combined movements, the maximum error was 2.6 (mean 1.2, SD 0.99) mm. The error of measurement depended on the chosen reference lines and was minimal for the distance shoulder-lesser trochanter (Table 1).

With EBRA-FCA, the maximum error of measurement was 0.4 (mean error 0.2, SD 0.13) mm, taking all 30 radiographs in random order. When the radiographs were taken in a consecutive order of tilt, the maximum error of measurement was 1.4 (mean 0.8, SD 0.56) mm for extension-flexion, 0.4 (mean 0.1, SD 0.14) mm for abduction-adduction and 0.7 (mean 0.3, SD 0.19) mm for internal- external rotation

Table 1. Tilt study, right hip: error of measurement with standard methods for all radiographs

	H.-major	H.-lesser	S.-major	S.-lesser
absolute mean	0,81	2,06	1,07	0,72
absolute median	0,57	1,14	0,70	0,66
max	2,92	7,46	4,10	1,96
SD	0,69	2,35	1,09	0,52

for the right hip. For the combined movements, the maximum error was 1.0 (mean 0.5, SD 0.41) mm.

From all radiographs, smaller samples with 2 to 5 radiographs were selected randomly, simulating a more realistic clinical situation. Only a few radiographs from the whole series were detected as tilted and excluded by the software. The maximum detected error was 1.7 mm. When four radiographs were taken with consecutive flexion of 0, 6, 12 and 16 degrees, these were defined as comparable by the software and the measured subsidence was 1.6 mm.

In the left femur, the stem was inserted more deeply into the femoral canal, the head centre being 1.5 mm below the tip of the major trochanter: Again, the radiographic enlargement was 1.2. When looking at the radiographs in 0 degrees and 16 degrees of flexion, the measured length of the stem on the radiographs differed by 0.8 mm.

With the standard measurements a maximum error of 4.3 (SD 1.71) mm was found for measurements of the shoulder in relation to the lesser trochanter (Table 2). The main error was produced by movements in extension-flexion (mean 1.2 mm, SD 1.10), followed by external-internal rotation (mean 1.7 mm, SD 1.13) and abduction-adduction (mean 1.1 mm, SD 0.66). For the combined movements, the maximum error was 2.8 (mean 1.4, SD 0.88) mm. Again, the error of measurement depended on the chosen reference lines and was minimal for the distance shoulder-major trochanter (Table 2).

With EBRA-FCA the error of measurement on the left side was less than on the right side. The maximum error of measurement was 0.2 (mean difference –0.03, SD 0.65) mm, taking all 30 radiographs in random order. When the radiographs were taken in consecutive order of tilt, the maximum error of measurement was 0.5 (mean 0.31, SD 0.16) mm for extension-flexion, 0.3 (mean 0.25, SD 0.11) mm

Table 2. Tilt study, left hip: error of measurement with standard methods for all radiographs

	H.-major	H.-lesser	S.-major	S.-lesser
absolute mean	0,64	0,94	0,27	1,44
absolute median	0,61	0,87	0,18	1,26
max	1,50	2,53	1,52	4,27
SD	0,42	0,73	0,33	1,00

Table 3. Subsidence study: error of measurement with standard methods for all radiographs.

	H.-major	H.-lesser	S.-major	S.-lesser
absolute mean	0,44	0,43	0,41	0,43
absolute median	0,40	0,32	0,34	0,33
max	1,59	1,59	1,08	1,87
SD	0,37	0,33	0,26	0,36

for abduction-adduction and 0.4 (mean 0.19, SD 0.09) mm for internal- external rotation for the left hip. For the combined movements, the maximum error was 0.5 (mean 0.3, SD 0.19) mm.

Selecting smaller samples of radiographs, the error was smaller than for the right femur.

2. Subsidence study

With the standard measurements, the most reliable reference line was from the shoulder of the implant to the major trochanter. The error of measurement was hardly affected by the chosen reference lines and the maximum error was 1.9 mm, using the lesser trochanter as reference (Table 3).

The maximum error using the EBRA-FCA method was 0.2 (0 to 0.2, mean 0.06, SD 0.05) mm. When subgroups of three to seven radiographs with increasing subsidence were selected, a maximal error of 0.5 mm was found.

An extreme situation was simulated with 5.0 mm initial subsidence on the first radiograph and a stable situation on further 29 radiographs. As there was no projection difference, all radiographs were comparable with EBRA-FCA and an initial subsidence of 0.8 mm without further progress was calculated. When the test was repeated with a lower number of radiographs, the error of measurement decreased and in the case of 6 radiographs, the measured subsidence with EBRA-FCA was 2.4 mm.

Discussion

It is recognized that the error of measurement for femoral subsidence depends on the range of motion of the femur but Walker et al. (8) thought that the error of measurement might be neglected within a range of 10° of flexion and rotation on the basis of theoretical calculations. We found a maximum error of measurement of 6.6 mm for 10° of flexion for the right hip but for the left hip and other reference lines, the error of measurement was lower. In a clinical situation flexion up to 10° might be found when the patient is developing a flexion contraction due to hip pain. Even in the most flexed and rotated position there were no obvious differences between the radiographs, thus in a standard clinical situation no radiograph would have been rejected due to excessive distortion and even in the case of minor distortion a considerable error of measurement could occur.

The difference in the results of the left and the right hip may be explained both by variations in the shape of the femur and in the position of the implant. On the left side, the femoral component was implanted in a more distal position, the head centre was closer to the major trochanter and the shape of the lesser trochanter changed more when rotated (7). For this purpose, Biedermann et al. (6) recommended in a theoretical model the major trochanter and the prosthetic shoulder as reference points. On the other hand, the major trochanter might be less reliable due to heterotopic ossifications in clinical analysis (3). For standard measurements, the optimal reference line would depend on the individual situation.

EBRA-FCA detected and excluded very few tilted radiographs out of our series of measurement because of the small projection differences. But, due to the comparing algorithm and the geometry of the reference lines, the EBRA-FCA measurements were less affected by eventual tilt of the femur and thus more accurate than the standard measurements. As for the cup (5), a systematic error of measurement due to consecutive tilt in one direction (flexion) could not be avoided and in this case the maximum error of measurement was found. In a random combination of radiographs, the error of measurement with EBRA-FCA was much less than with standard methods.

In the subsidence study, all standard measurements were reliable because the shape of the bony structures remained unchanged. In a clinical situation the detection of these structures and correct drawing of the trochanter lines would be even more difficult and the error of measurement will increase.

With EBRA-FCA, linear subsidence could be measured very accurately. In the case of initial high subsidence and a following stable situation of identical radiographs, all radiographs were compared and the mean subsidence was calculated, underestimating the actual subsidence. No measurement exceeded the actual subsidence. There were no false positive results and EBRA tends to underestimate the actual subsidence. EBRA-FCA has a higher specificity than sensitivity for detecting subsidence (1, 9).

The pattern of subsidence is of major importance for predicting the late outcome of the implant (1, 2). It was correctly described with EBRA-FCA and EBRA-FCA seems to be reliable in detecting stable implants in the mid-term.

Conclusions. Effects of tilt are more difficult to detect on radiographs in the femur than in the pelvis and EBRA-FCA is less accurate for femoral assessment than EBRA is for the cup. Biedermann et al. (6) could demonstrate that EBRA-FCA improves the measurement accuracy as compared to standard methods in the clinical situation. It is reliable for the detection and description of the patterns of subsidence and the measurements are of prognostic value. Early implant movements like initial settlement of the stem can not be detected and described with EBRA-FCA. Analysis of single patients and radiographs in the early postoperative phase has to be done with radiostereometry.

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