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ORIGINAL STUDY

Assessment of femoral component migration in total hip arthroplasty : Digital measurements compared to RSA

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The aim of this study was to determine the accuracy of the software system "Düsseldorf Migration Analysis – Femoral Component Analysis" (DMA-FCA) in measuring stem migration in total hip arthroplasty (THA) on digitised anteroposterior radiographs of the pelvis. Bony and implant landmarks on two consecutive radiographs were used for measurements of subsidence and varus-valgus tilt.

The accuracy of the method was determined by reference to radiostereometric measurements (RSA). Using specific comparability limits, comparability analysis of radiographs with respect to femoral positioning is possible with DMA.

DMA-FCA and RSA measurements were performed after cementless THR in a population of 60 patients aged 38 to 69 years. With a Cronbach's alpha-index of 0.89 and 0.99 for subsidence and 0.90 and 0.98 for classic varus-valgus-tilt, the intraobserver and interobserver reliability for the DMA-FCA-method was calculated as good. Using RSA as reference method, the accuracy of DMA-FCA was calculated to be 2.51 mm for subsidence and 2.49° for varus-valgus-tilt (95% confidence interval). Without comparison to RSA, DMA measured 1.94 mm for subsidence and 2.35° for varus-valgus-tilt.

Based on a comparison with RSA, our results show lower accuracy for DMA-FCA than for EBRA-FCA, but DMA-FCA is easier to use in everyday clinical practice. It is hoped that the use of digital measuring methods such as DMA will become standard for long-term observation and will be integrated into clinical routine in the context of quality assurance of THR.

INTRODUCTION

Diagnostic procedures to check for implant loosening in total hip arthroplasty (THA) are based on the clinical situation and the radiological follow up. Mjöberg (*26*) considered early migration of acetabular implants as indicating lack of primary stability, which would result in loosening. The prognostic value of early recognition of migration of the acetabular cup has been demonstrated by several authors (*21, 38*). Their results suggest that the most accurate method gives the highest probability of predicting early loosening which will lead to failure of the arthroplasty.

Loosening mechanisms for femoral components are complex. Aseptic loosening of uncemented

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femoral implants, in particular, often causes diagnostic problems (*19, 31*). Multiple factors affect secondary stabilisation which may occur after inital migration, and initial stability may also be followed by late subsidence (e.g. polyethylene wear particles in the synovial fluid (*34*), distal foreign body reaction and granulomas (*20*), progressive osteopoenia and cortical thinning, geometry of the implant). Because of these factors, the early measurements of migration refer to lack of initial stability, but cannot address all mechanisms of loosening. Donelly *et al* (*8*) found considerable differences in the migration curves for successful and less successful stems.

Early migration of prosthetic stems and cups is often assumed to predict later failure (*10, 21*). A correlation has been noted between subsidence of the femoral stem of more than 1-2 mm two years after THA and a significantly higher probability of implant failure in later years (*1, 16, 41*). Highly accurate methods of measurement are needed to achieve predictive value. Several radiological techniques have been developed, but they use different reference lines and have varying accuracy. Different reference points on the implants and the bone have been used. One or more reference lines describing migration and tilt on conventional radiographs are being used. Malchau *et al* (*25*) compared four different reference lines. Common bony reference points are the greater trochanter (*35, 39*) or the lesser trochanter. Reference points on the femoral implant are the centre of the head (*28, 35, 39*), the distal tip of the stem (*11*), the proximal end of the stem (*3*), a lateral point on the collar (*41*) or the lowest margin of the collar.

The accuracy of the methods varies (table IV). Sutherland *et al* (*35*) required a change of over 5 mm in the positioning of the femoral component to ascertain migration with their method. The "gold standard" RSA (Roentgen Stereophotogrammetric Analysis) is reported to have an accuracy of about 0.2-0.4 mm for subsidence (*9, 26, 36, 37*) (table IV). The EBRA method ("Einzel-Bild-Röntgen-analyse", single radiological analysis) has 1-mm confidence limits for measuring acetabular component migration (*18*) ; for femoral component migration measurement, EBRA-FCA (Femoral Component Analysis) has a demonstrated accuracy of 1.5 mm (*1*) (table IV). This method has also been shown to have predictive value for failure (*19*).

In this study, we illustrate the accuracy and reproducibility of a software system for stem migration measurement. The DMA-method ("Düsseldorf Migration Analysis"), first mentioned and developed by Müller *et al* (*27, 28*), allows analysis of the migration of the acetabular component (DMA-ACA ; DMA-acetabular component analysis) and of the femoral component (DMA-FCA ; DMA-femoral component analysis). On two consecutive digital or digitised radiographs, DMA-FCA calculates subsidence and varus-valgus-tilt of femoral THA components according to bony landmarks and geometric comparability parameters.

Accuracy is the parameter which describes the agreement of reality with measurement results. Analysis of the accuracy of certain methods is made by the comparison of measurements with known true dimensions. Unfortunately, accuracy is difficult to assess because the real position of the implant often is not known exactly. There are several possible ways to evaluate the accuracy of specific measurement methods (*22*). The aim is the detection and limitation of various measurement errors (patient positioning, projection differences, radiological quality) and elimination of systemic measurement errors. Measurements have been made on radiographs of phantoms, which permitted an exact simulation of migration procedures (*4, 7*). Another method was discussed by Wetherell *et al* (*42*) for the first time. They made measurements on radiographs of bone models with stable positioning of the femoral prosthesis and studied the effect of rotation in various planes. Several studies which employed this method for accuracy analysis were carried out to assess the migration of acetabular components (*6, 18, 31, 32*). Modern CAD-technique combined with a femoral model was used by Biedermann *et al* (*1*) for accuracy analysis of the EBRA-FCA-method in measuring femoral component migration. Calculation of the apparent migration on different radiographs of the same patient within a very short time period often leads to an underestimation of the measuring error (*1, 18, 29, 30*). A method of analysis which takes into account

Table I. — Intra-observer analysis (mean, SD values) of five implants

Stem type	Antega™	ESKA™	Optan™	CLS Spotorno	Straight Müller
	Mean (SD) [mm]	Mean (SD) [mm]	Mean (SD) [mm]	Mean (SD) [mm]	Mean (SD) [mm]
SI	-0.02 (+/- 0.28)	0.04 (+/- 0.45)	-0.01 (+/- 0.18)	0.01 (+/- 0.13)	0.01 (+/- 0.11)
VVA	-0.01 (+/- 0.11)	0.03 (+/- 0.18)	0.01 (+/- 0.08)	-0.02 (+/- 0.05)	-0.03 (+/- 0.09)
VVAC	-0.02 (+/- 0.08)	0.01 (+/- 0.13)	-0.01 (+/- 0.10)	-0.01 (+/- 0.03)	0.02 (+/- 0.08)

Antega™ : Aesculap, Germany ; ESKA™ : ESKA Implants, Germany ; Optan™, CLS™, Müller straight stem : Centerpulse, Switzerland.

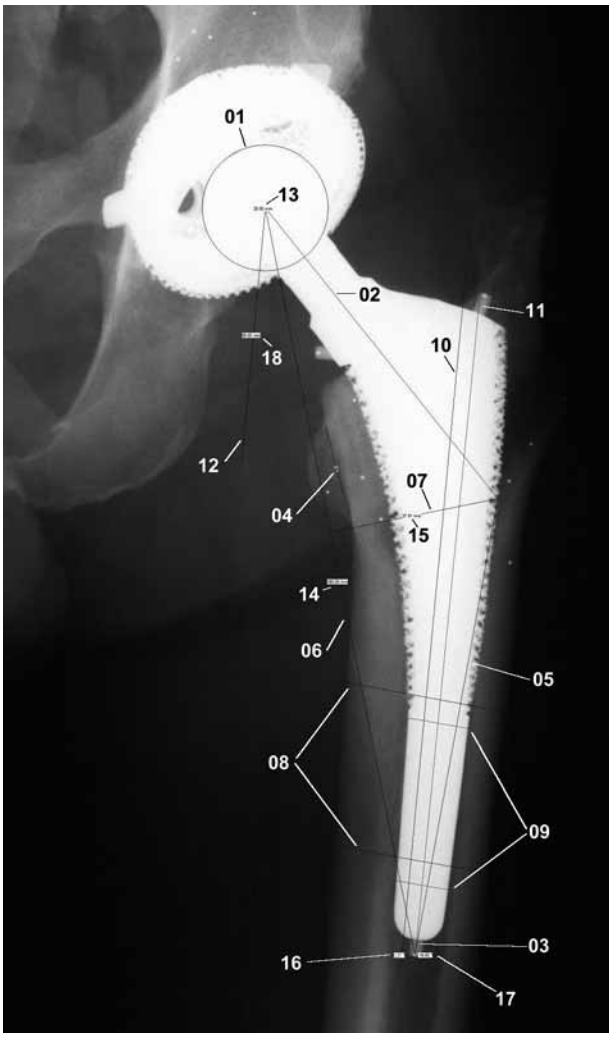
implausible results (caudal migration of cup or cranial migration of stem) has a limited applicability and very often yields an underestimation of measuring errors (*1, 22*). Another way is the comparison with a more exact method, the "golden standard". This method was often used to evaluate accuracy (RSA in migration analysis of THR (table IV)). Like Ilchman *et al* (*13*), who compared four different radiological methods for migration of the acetabular component with RSA, we determined the accuracy of DMA-FCA in measuring stem migration by comparing with the corresponding data determined with RSA.

PATIENTS AND METHODS

To analyse intra-observer variability of DMA-FCA, 5 pairs of pelvis radiographs showing 5 different implanted stem designs (table I), were measured over a period of two months. During these two months, one investigator carried out five DMA-FCA measurements on every radiograph pair (= 125 measurements). Discrepancies in measurement values therefore only reflect intra-observer variability, as the five measurements have been done on the same uniplanar radiographs. For the calculation of interobserver reliability, two experienced investigators measured independently from each other 10 series of 6 pelvis radiographs (= 60 measurements) three times. The mean value of the three measurements was taken as the measured value of each investigator. The mean difference in the value of each DMA-FCA parameter for all radiographs was taken for the estimation of the interobserver accuracy of the measuring system. The intra- and interobserver reliability wax expressed by the Cronbach alpha index.

Porous structured cementless ESKA-G2-stems (ESKA™ Implants, Germany) were implanted from 1998 until 2000. For 60 patients (28 male and 32 female, aged 38-69 years), RSA examinations and pairs of conventional anteroposterior radiographs were aquired. None of the patients showed obvious radiological signs of migration or loosening. All baseline examinations (both RSA and conventional radiographs) were performed between the 10th and 14th postoperative day. Follow-up examinations were performed at 6 (n = 29), 12 (n = 22), or 24 (n = 9) months postoperatively. The subsidence and the varus-valgus tilt of the 60 cementless stems between baseline and follow-up examinations were separately measured on the conventional radiographs with the DMA-FCA-method and also with RSA. Due to poor film quality, the femoral head diameter could not be determined correctly in 5 cases for DMA-FCA. The differences between DMA-FCA results and those obtained by the corresponding RSA examinations were calculated in 55 cases.

RSA makes an exact three-dimensional measurement possible (*33, 36, 37*). The three-dimensional kinematics of implant movements can be determined by repeated examinations. RSA was executed in four steps : First, spherical tantalum markers (∅ 0.8 mm) were installed at the time of the implantation of the ESKA prosthesis using a stainless steel insertion instrument. Titanium pegs with inlaid spherical tantalum markers were inserted into the shoulder, the collar, and the tip of the implants during the manufacturing process (fig 1). The two sets of tantalum markers (femur and implant) clearly define the spatial position of both moving segments.



Subsidiary lines/points. Implant and bone markers defined by user :
01 : Diameter of the implant head (marking circle) ;
02 : Centerline of prosthetic collar : The user draws a roughly vertical intersection line through the parallel edges of the stem collar. The system then offers a central line, from the center of the prosthetic head, through the center of the intersection line of the prosthetic collar to the intersection point of central line with the lateral edge of the prosthetic stem. A manual correction is possible ;
03 : Tip of stem ;
04 : Femoral reference point : Midpoint of an intersection line at the lesser trochanter if a clear reference point is not determinable.
Parameters calculated automatically by the DMA-software :
Completion of the stem rotation triangle (SRT), defined by the following lines : Centerline of prosthesic collar (02) ;
05 : line between lateral intersection point of centerline of collar with stem edge and tip of stem (03) ;
06 : stem length equivalent (SLE) : line from center of prosthetic head (01) to tip of stem (03) ;
07 : Height of SRT (HSRT) : The perpendicular to SLE (06) through the intersection point of the centerline of the collar with the stem edge and the tip of the stem (03) ;
08 : femoral intersection lines for determination of femoral axis (10) ;
09 : stem intersection lines for determination of prosthetic stem axis (11) ;
10 : femoral axis : Intersection line through the midpoint of the two femoral intersection lines (08) ;
11 : prosthetic stem axis : Intersection line through the midpoint of the two stem intersection lines (09) ;
12 : subsidence (SI) line : Parallel to stem axis (10) from center of prosthetic head (01) to femoral reference point (04)
Visible values :
13 : value of diameter of prosthetic head (01) ;
14 : value of SLE (06) ;
15 : value of HSRT (07) ;
16 : value of varus-valgus-angle (VVA) : angle enclosed by SLE (06) and femoral axis (10) ;
17 : value of classic varus-valgus-angle (VVAC) : angle enclosed by prosthetic stem axis (11) femoral axis (10) ;
18 : value of subsidence (12).

Fig. 1. – DMA-FCA

The second step is the radiograph investigation : 2 X-ray tubes are positioned 35° to 40° angled to each other so that their centre beams cross within the femoral implant. Both film cassettes are put in a calibration cage under the examination table. The cage is equipped with spherical tantalum markers in two spatial planar levels, defining a three-dimensional coordinate system. It is used to determine the position of the two X-ray foci. Both radiographs are taken simultaneously. In step three, both radiographs are digitised, and the implant markers, femur markers and the markers of the calibration cage are plotted by the PC-based RSA-software (UMRSA™, RSA BioMedical Innovations AB, Umeå, Sweden). Using the stereometric radiographs obtained, the RSA-software then calculates the relative movement between the implant and the femoral bony segment (*17*). The calculations show changes in absolute and relative positions of the implants with a demonstrated accuracy of 0.1-0.2 mm (*17*).

DMA (GEMED Ltd., Ulm, Germany) permits an assessment of the pelvic and femoral spatial orientation and the measurement of cup and stem position using reference bone landmarks. It makes it possible to assess cup and stem migration despite projection differences due to variations in patient positioning during the radiological procedure. To correct for magnification, the analysis software is calibrated by reference to the known head diameter of the implant. Stem analysis (DMA-FCA) can be carried out independently from acetabular analysis (DMA-ACA). The measurement of stem positioning is carried out in two steps. First, specific stem lines and points are fixed by the investigator : the centerline of the collar and the tip of the stem. The femoral reference point for subsidence is defined at the region of the lesser trochanter. The system then calculates various parameters : the so-called stem rotation triangle (SRT) and the height of SRT (HSRT). HSRT allows comparison of femoral position with respect to its rotation. The hypothenuse of SRT, called the stem length equivalent (SLE) is also calculated. SLE permits comparison of the femoral position in the sagittal plane (flexion-extension). In the same step, the system automatically defines the axis of the femur and of the stem (*27*). In a second step, the midpoint of an intersection line at the lesser trochanter is determined as a femoral reference point. The system then calculates the femoral position automatically. Migration of the stem is determined by calculating the subsidence (SI) as the change in the measured distance between the lesser trochanter reference point and the center of the femoral head. There are two different methods to determine the varus-valgus-angle (the measured VVA and the classic varus-valgus-angle (VVAC). For the definition of parameters and reference lines/points, see fig 1. The effect on the accuracy of the system of using metal markers inserted into the femur instead of using the lesser trochanter as a femoral landmark, was assessed by calculating subsidence from the distances between femoral metal markers and the center of the implant head.

Faults in measuring implant migration are most frequently caused by variations in the positioning of the hip joint with respect to flexion and rotation during the individual radiograph examinations (*41*). Therefore, DMA uses two parameters to assess the comparability of pairs of radiographs, HSRT and SLE (fig 1), and only accepts pairs of radiographs in which the values of HSRT and SLE remain with chosen limits. The results of every radiograph measurement are verified taking into account the comparability parameters. After measurement of a series of radiographs, the final value is calculated from the individual results of all accepted radiographs. For the SLE as a parameter for the interpretation of femoral rotation about a tranverse axis (flexion-extension), the comparability is set at 5 mm. For assessment of the femoral rotation around the longitudinal axis, the comparability limit is set at 3 mm for the HSLT. Radiographs showing values which exceed the defined comparability limits were not accepted for measurement and were eliminated.

In all radiographs, the change in position of the femoral implant, as compared to the immediate postoperative position, was measured using the DMA-FCA-method regarding subsidence and VVAC. These values were then corrected by subtracting the "true" position, considered to be the corresponding RSA value at the same specific time (migration according to DMA minus migration according to RSA). All differences in migration measurement between RSA and DMA were defined as inaccuracies of the DMA method. The mean values and the standard deviations of the absolute differences between values obtained with the DMA-method and the corresponding RSA values were calculated. They reflect the accuracy of this method in comparison to RSA. The range of inaccuracy corresponds to the 95% confidence interval (95% CI). This definition of accuracy applies to all parameters measured. At the time of the DMA analyses, the results of RSA were not known to the investigators. To determine how metal markers in the lesser trochanter instead of digital DMA-reference point influenced the accuracy of the method, Levene's test for comparison of variances was used. The same test was used to evaluate the effect of using comparability limits for rejection of radiographs on DMA-FCA accuracy.

A correlation coefficient is necessary for the interpretation of the dependence between DMA values and RSA values of the examined parameters. The practical parameter for the description of scatter-plot consistency is the Intraclass-Lin-Correlation coefficient (ICC_{LIN}) (*23*) :

$$ICC_{LIN} = \frac{2 \,.\, r_{Pearson}}{\left(\frac{SD_A}{SD_B} + \frac{SD_B}{SD_A} + \frac{(m_A - m_B)^2}{(m_A \,.\, m_B)} \right)}$$

SD : standard deviation ; m : mean ;
A : investigation group A (here DMA) ; B : investigation group B (here RSA) ;
$r_{Pearson}$: Pearson correlation coefficient (on its own $r_{Pearson}$ is not appropriate for the description of deviations of scatter-plot from the bisecting line)

RESULTS

With respect to intraobserver reliability, Cronbach's alpha values of 0.99 for subsidence and 0.98 for VVA and VVAC were calculated. No significant differences were noted between different stem designs. The mean difference in subsidence over all measurements is 0.01 mm (SD +/-0.39 mm). The mean value for VVA was calculated to be –0.2°, and the mean value for VVAC was 0.01° (SD

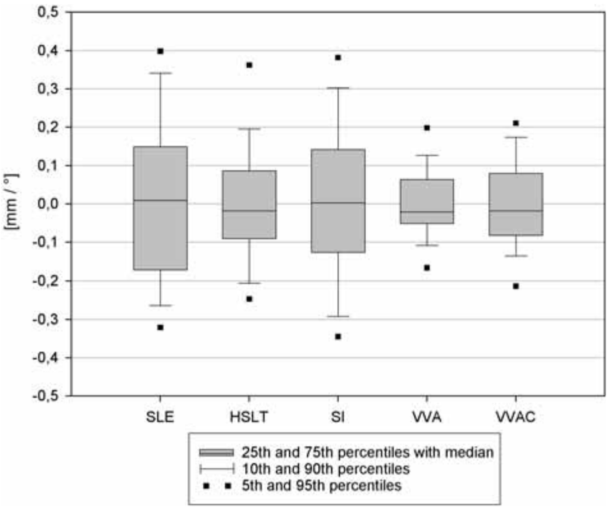


Fig. 2. — DMA-FCA intraobserver-differences

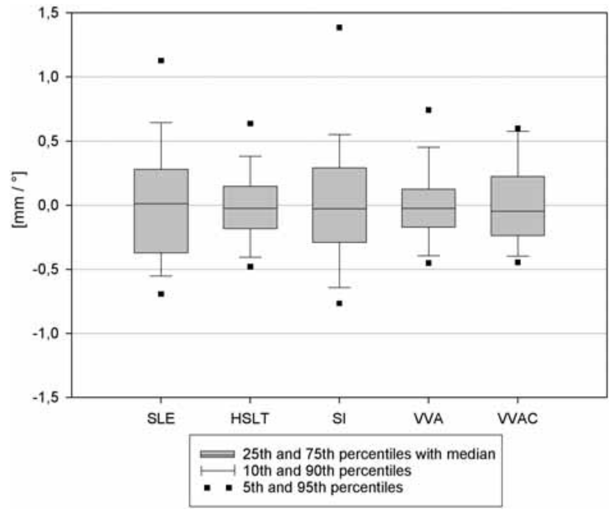


Fig. 3. — DMA-FCA interobserver-differences

0.19° and 0.22° respectively). Median, interquartile, 95% percentile ranges and minimum/maximum values are shown in fig 2. The results for each of the five femoral implants are listed in table I.

Cronbach's alpha for interobserver reliability was 0.89 for subsidence, 0.91 for VVA and 0.90 for VVAC. The median, interquartile, 95% percentile ranges and minimum/maximum values of each parameter between the two investigators were determined (fig 3). The mean difference in subsidence was 0.12 mm (SD +/-1.36 mm). Calculation of VVAC showed a mean value of 0.24°, for a VVA of -0.1°.

Table II shows the accuracy for DMA-FCA-method for subsidence (SI) and table III for varus-valgus-tilt of stems. Twelve of the 55 pairs of radiographs were excluded from the examination owing to non-comparability. Without consideration of RSA, the mean subsidence measured by DMA was 2.7 mm without comparability limits and 1.94 mm using comparability limits. With reference to RSA, the accuracy for subsidence was calculated to be 2.51 mm using comparability limits. The measured and calculated mean difference, 95%-CI and min./max. values are shown in fig 4. When comparability limits were used, the measured VVAC was 2.4°, the VVA 2.8°.

The difference in accuracy of DMA measurements with and without the use of comparability limits was not significant when bony landmarks ($p = 0.065$) or metal markers ($p = 0.091$) were used. Comparison of the calculated 95% CI for subsidence measurement when using either a tantalum reference marker or a defined bony marker at the lesser trochanter showed a difference of 0.2 mm (fig 5). Differences in accuracy using the lesser trochanter versus metal markers as femoral landmarks were not significant ($p = 0.081$ using comparability limits, $p = 0.121$ without comparability limits).

For subsidence ICC_{LIN} was calculated to be 0.2 without comparability limits and 0.23 with comparability limits. For VVAC and VVA see table III.

DISCUSSION

Aseptic loosening of the femoral stem after THR is associated with component migration in most cases. For several cementless designs, migration of $\geq$ 2 mm was shown to correlate with a higher risk of loosening (*34*). For cemented Lubinus SP1 stems (Link, Germany), the risk of revision was 95% if migration exceeded 2.6 mm two years after implantation (*11*). In order to detect such minimal component migrations, systems with high accuracy are needed. A statistical comparison of studies performed with different methods to measure migration of femoral components after THR is difficult.

Table II. — Measured and calculated subsidence (DMA-FCA, RSA)

	n	Mean [mm]		95%-CI [mm]		ICC_{LIN}
DMA		abs	calc	abs	calc	
Subsidence measured from lesser trochanter to head center						
SI without comparability limits	55	0,26	0,08	2,70	2,98	0,20
SI with comparability limits	43	0,23	0,14	1,94	2,51	0,23
Subsidence measured from tantalum markers to head center						
SI without comparability limits	55	0,15	0,08	2,12	2,23	0,29
SI with comparability limits	43	0,11	-0,16	2,06	2,31	0,26
RSA	55	0,12		0,51		–

SI : subsidence, (negative=distal, positive=proximal) ; **abs**. : measured value ; **calc**. : calculated value (subtraction of RSA-value from measured DMA-FCA-value) ; **SD** : standard deviation ; **CI** : confidence interval ; ICC_{LIN} : Intraclass-Correlation-coefficient.

Table III. — Measured and calculated values for VVA and VVAC (DMA-FCA, RSA)

	n	Mean [mm]		95%-CI [mm]		ICC_{LIN}
DMA		**abs**	**calc**	**abs**	**calc**	
VVA without comparability limit	55	0.05	0.48	4.70	3.65	0.32
VVA with comparability limit	43	0.15	0.42	3.84	2.84	0.39
VVAC without comparability limit	55	0.10	0.35	3.63	2.76	0.35
VVAC with comparability limit	43	0.13	0.39	2.49	2.35	0.41
RSA	55	-0.28		1.25		–

VVA : varus-valgus-angle ; **VVAC** : classical varus-valgus-angle (positive = valgus, negative = varus) ; **SD** : standard deviation ; **CI** : confidence interval ; ICC_{LIN} : Intraclass-Correlation-coefficient ; **abs** : measured ; **calc** : calculated by comparing the measured DMA-values with the reference method RSA.

Müller *et al* (*27, 28*) gave no information about intra- or interobserver variability of the DMA method. Our measured accuracy regarding intraobserver variability was 0.01 mm for subsidence and 0.01° for VVAC. These differences are negligible in the analysis of a series of radiographs. The accuracy of interobserver analysis excluding radiological factors was calculated to be 0.12 mm for subsidence and 0.24° for VVAC. In agreement with other authors (*1, 15, 42*), these results show that radiological factors like projection differences and poor radiological quality have the largest influence on the accuracy of methods which use uniplanar migration analysis. The main reason for the inaccuracy of conventional measuring is considered to be variations in the positioning of the hip and/or stem in a series of radiograph (*41*). Several studies, mainly from Ilchman (*13, 14, 15*) on cup migration showed that comparability analysis of radiographs is a good tool to reduce the inaccuracy in conventional radiological measurement. Rotation of the hip influences the apparent position of femoral component. Todd *et al* (*40*) demonstrated the potential for apparent migration of femoral prostheses depending on rotation of the lower extremity. The application of comparability limits of the DMA-FCA software (SLE : 5 mm, HSRT : 3 mm) led in 22% of the cases to identification of non-comparable radiograph pairs. Rejection of these radiographs improved the accuracy by about 0.5 mm.

Another way to optimise the accuracy of a measurement method on conventional radiographs is the use of adequate reference landmarks. Malchau *et al* (*25*) showed variations from 4 mm to 10 mm in

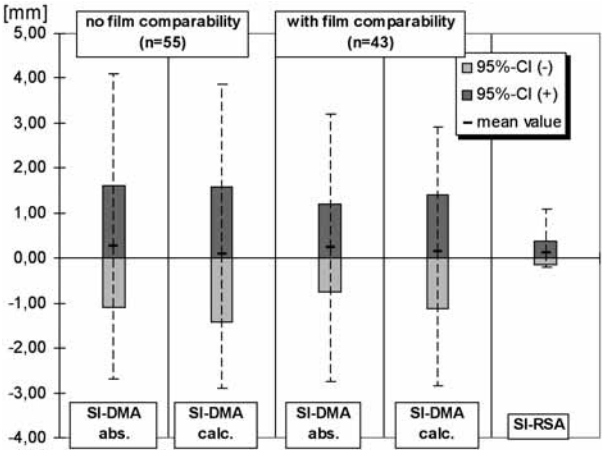


Fig. 4. — Accuracy for subsidence.
SI abs. : Subsidence measured with DMA ;
SI abs. acl. : Subsidence calculated by subtraction of RSA from SI abs.

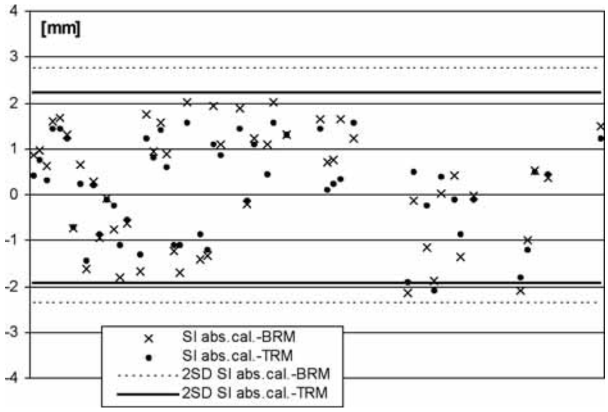


Fig. 5. — Subsidence measured using bony and tantalum reference marker at lesser trochanter.
SD : standard deviation ;
SI : subsidence ;
abs. cal. : calculated by subtraction of RSA from SI abs. ;
BRM : bony reference marker ;
TRM : tantalum reference marker.

measurement of stem migration, depending on the choice of the reference landmarks on conventional radiographs. Walker *et al* (*41*) indicated that reference points lying closer to each other on stem and femur, are best for determining migration. Using the same series of radiographs and RSA examinations, an accuracy of +/-2.5 mm (95%-CI) regarding migration measurements between the most medial point of the lesser trochanter and the tip of the stem was calculated for Ulmer Migration Analysis method (UMA) (*5*). Measuring between the lesser trochanter and the femoral head center, as done in this study, apparently did not change the accuracy. A CAD experiment of Biedermann *et al* (*1*) pointed that the lesser trochanter was the worst and the tip of the greater trochanter near the shoulder of the femoral prosthesis was the best reference point for measuring subsidence with the EBRA-FCA method. Unlike these authors, Braud and Freeman (*3*) indicated that rotation of the femur had only little influence on measuring differences.

Compared with the use of bony markers as femoral landmarks, the use of metal markers improved the system accuracy. We could demonstrate that the choice of the lesser trochanter as a bony reference increases inaccuracy (95%-CI) by about 0.2 mm in comparison with fixed tantalum marker reference points. However, the difference between the two methods was not statistically significant with the number of cases studied. Biedermann *et al* (*2*) did not find any significant improvement in the accuracy of migration measurement by using tantalum markers instead of bony landmarks, but Malchau *et al* (*25*) came to the opposite conclusion.

Ilchman *et al* (*13*) mentioned that the comparison of a measurement method with RSA often shows lower accuracy. The calculation of the accuracy of the DMA-FCA by comparison with RSA led to a worse value for subsidence than the absolute measurement with simple analysis of radiographs. If we assume that there is non-subsidence of the ESKA stems on the analysed radiographs, then we could conclude, that our measured absolute value reflects the system accuracy more precisely than the data matched with RSA. However, we are not certain that this is valid. The ICC_{LIN} value for correlation between RSA and DMA is low. Most likely, this is because of small migration values due to the short follow-up (6 to 24 months) and the problem of comparing three-dimensional measurements (RSA) to two-dimensional measurements (DMA). From the interpretation of these results the following question is raised : Is the method described by

Table IV. — Comparison of methods frequently used to measure stem subsidence in THA

	No. of cases (n). radiographs (nr)	Accuracy [mm]	Evaluation method
Manual methods			
Sutherland *et al* (*39*)	–	estimated : +/- 5	clinical radiographs
Walker *et al* (*41*)	–	maximal error : 0.37 (apparent migration)	rotating modell
Digital methods			
MAXIMA Hardinge *et al* (*11*)	–	estimated : +/- 0.5	not mentioned
Digital methods with comparability analysis			
UMA Decking, Schütz *et al* (*5*)	n = 60 nr = 110	SI +/- 2.5 VVA : 1.8°	compared with RSA
DMA Müller *et al* (*28*)	–	estimated : +/- 1	not mentioned
DMA-FCA Schütz *et al*	n = 55 nr = 110	SI +/- 2.5 VVA : 2.5°	compared to RSA
EBRA-FCA Biedermann *et al* (*1*)	max. changes –5° to +20°	mean : 1.5 SI +/- 1.4	CAD-simulation : Pelvis model
	n = 8 (series)	SI +/- 1.6	compared with RSA
	nr = 33	SI -1.1 - +0.8	x-ray film at same time
	nr = 1163 n=117	SI +/- 0.9	apparent upward migration
	All series above	SI +/- 0.87	interobserver variation
RSA			
Several authors (*9, 25, 36, 37*)		SI mean : 0.1-0.2	–

Krismer *et al* (*22*) which compares a uniplanar digital measuring (EBRA-FCA) with the three-dimensional method RSA suitable for accuracy validation of EBRA-FCA ? Further studies are necessary to elucidate this point.

Therefore, it is reasonable to believe that the accuracy of DMA-FCA is better than 2.5 mm. This is different from the results of Müller *et al* (*28*) (1-1.5 mm), which may result from using different methods to evaluate accuracy. So Müller *et al* (*27*) did not indicate any details regarding their method for accuracy analysis. For their Manchester radiograph image-analysis system (MAXIMA) Hardinge *et al* (*11*) claimed an accuracy of +/- 0.5 mm, but they did not describe how this value was determined. By comparing the results with RSA, Malchau *et al* (*25*) assessed the accuracy of measurements of migration on conventional and digitised radiographs of THR. The accuracy varied from 3.9 to 12.3 mm (absolute mean +2 SD). There are few published results of migration analysis of the femoral component regarding the varus-valgus position. We measured a mean value of 2.4-2.5° for the classical VVA. Regarding the special VVA of DMA (“16”, fig 1) it ranges from 2.8° (direct measurement) to 3.6° (comparison with RSA). This difference is also justified by a low ICC_{LIN} which points to the same questions regarding possible methodological problems, as discussed for subsidence.

Long-term revision rates are important outcome measurements, since they differ considerably between different implants in hip registries (*12, 24*). The amount of migration that leads to implant loosening is discussed in the literature with considerable controversy. In most publications this threshold depends on the accuracy of the employed method. Walker *et al* (*41*) reported migration of less than 2 mm after two years in 76% of successful stems and more than 2 mm in 84% of failed stems.

Kärrholm *et al* (*16*) found that if the Lubinus prosthesis showed a subsidence of more than 1.2 mm at two years, the probability of revision was greater than 50%. Freeman *et al* (*10*) found a specificity of 86% and a sensitivity of 78% for failure prediction using a threshold migration of 1.2 mm per year. The significance of measured migration also varies with the type of femoral component. Measurement of initial migration can help to predict long-term outcome, and new implants should be evaluated with these methods.

Analysis with EBRA-FCA as shown by Krismer *et al* (*19*) indicates four different patterns of migration : early onset followed by continued subsidence (A), early onset with subsequent stabilisation (B), initial stability with late onset of subsidence (C) and stability throughout the period of observation (D). Further studies are necessary to assess the validity of these findings.

CONCLUSIONS

Measurement of femoral stem subsidence after THR takes an important place in the diagnosis of implant loosening. The method presented here tries to combine user-friendliness with improved accuracy in clinical practice. The DMA-FCA method uses pairs of radiographs of the operated hip joint with one baseline and one follow-up examination. The software analyses digitised or digital radiographs ; the user must fix only the head diameter and three reference points on the femur. DMA-measurements take only two minutes for one patient. The migration data are calculated and permanently stored in the system database for long-term migration studies. Our analysis shows an accuracy of DMA-FCA better than 2.5 mm for component subsidence. DMA-FCA is easy to use in larger patient groups in the context of prospective and retrospective studies, whereas RSA is limited to small prospective studies (invasive, expensive, and complicated).

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