The accuracy of measurements of femoral neck fractures.

Conventional radiography versus roentgen stereophotogrammetric analysis

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Postoperative displacement of the femoral head center was measured in 60 intracapsular hip fractures at repeated conventional radiographic (CR) and roentgen stereophotogrammetric (RSA) examinations. The measurements of the conventional radiographs (405 pairs) were done on a digitizing table. Totally, 105 pairs of these radiographs (AP and lateral, CR) were measured by 2 observers. Manual measurements were also made on 176 pairs of the conventional radiographs. Conventional radiographs tended to overestimate or underestimate the average displacements up to about 2 mm. Two standard deviations of the differences (RSA-CR) varied from 5.8 to 9.6 mm depending on the direction of the movements. The accuracy of the measurements on conventional radiographs did not differ between the 2 examiners. The digitizing table was found to be more accurate than the manual measurements. The accuracy of conventional radiography can most likely be improved by using a strictly standardized examination technique.

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The shortening of femoral neck fractures has been evaluated by measurements based on implant geometry and anatomic landmarks (Edholm and Thorling 1981) or as extrusion or telescoping of the fixation device used to immobilize the fracture (Charnley et al. 1957, Rydell 1964, Fielding 1980). The accuracy of such measurements has not been evaluated.

We report a comparison between measurements of conventional radiographs and roentgen stereophotogrammetric analysis (RSA, Selvik 1974, 1989) in the evaluation of postoperative shortening in femoral neck fractures.

Patients and methods

Sixty patients with femoral neck fractures were evaluated. Sixteen fractures were internally fixated with two cannulated titanium screws (ACE®) and 44 fractures with one or two hook-pins (Hansson 1982) with or without a plate anchored to the distal pin. The median follow-up time was 1 year (1 week–2.5 years).

RSA

Peroperatively, four to six 0.8-mm tantalum markers were inserted in the femoral head and the trochanters for the RSA measurements. Medial-lateral, proximal-distal, and anterior-posterior translations of the center of the femoral head were measured (Ragnarsson et al. 1989, 1991); and for the purpose of the present study, the error of RSA was disregarded (Ragnarsson et al. 1989).

Conventional radiography

Radiographs were exposed in the routine AP and lateral projections.

The measurements of the conventional radiographs were performed on a digitizing table connected to a personal computer supplied with the necessary software (Research Metrics®). The radiographs were positioned with the longitudinal axis of the femur parallel to the Y-axis of the digitizing table. All the radiographs were positioned in the same way disregarding left-right side to facilitate the calculation of medial-lateral and anterior-posterior movements. The radiographic magnification was determined by measuring the known diameter of the osteosynthesis,

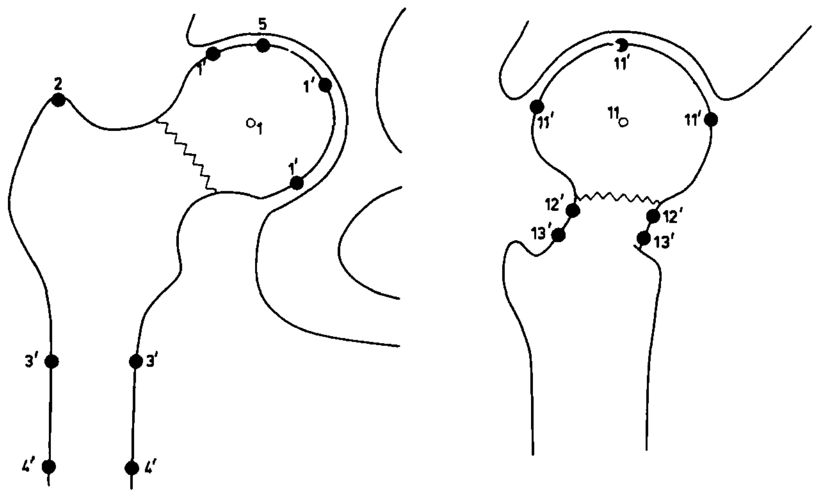

Figure 1. Digitized (filled signs) and calculated (unfilled) points on the AP and lateral radiographs.
The three 1' and 11' points were used to calculate the femoral head center (1, 11). Points 2 and 5 are the most proximal points of the greater trochanter and the femoral head. Points 3' and 4' and 12' and 13' were used to calculate two midpoints in the femoral shaft and the cervical neck (3, 4, 12, 13 in Figure 2).

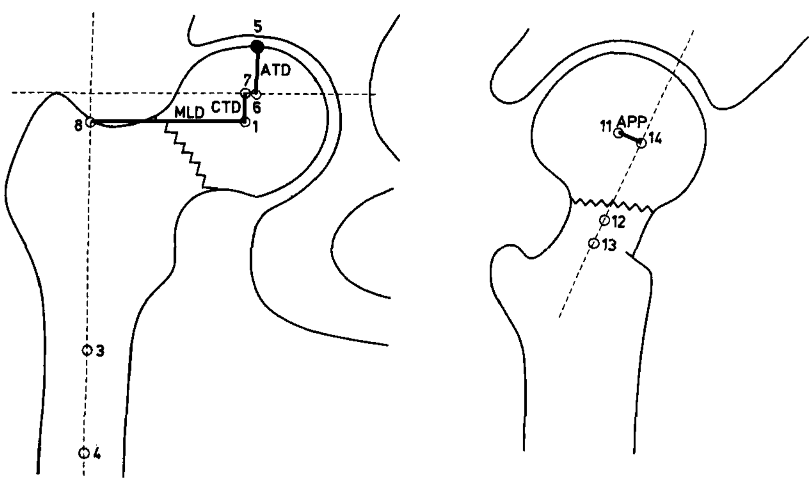

Figure 2. The points (unfilled signs) and lines (broken) calculated by the program to obtain the MLD (distance between points 1–8), ATD (distance 5–6), the CTD (distance 1–7), and the APP (distance 11–14).

whereupon the software eliminated the magnification.

On the AP view, three points were set at the femoral head circumference (points 1', Figure 1) to calculate the femoral head diameter and the position of the femoral head center (point 1). The tip of the greater trochanter was digitized (point 2). Two medial and two lateral reference points were set at the external femoral cortex, the first pair immediately below the lesser trochanter and the second one as far distally as possible (points 3' and 4'). Finally, the position of the most proximal part of the femoral head circumference (point 5) was measured.

On the lateral view, three points were set on the femoral head circumference (points 11' in Figure 1) enabling computation of the femoral head center (point 11) by the software. Four points were set at the outer cortex of the femoral neck: one pair as far proximally (points 12') and the other pair as far distally (points 13') as possible.

The software used the coordinates of these points to calculate the center lines of the femoral shaft (through points 3 and 4, Figure 2) and neck (points 12 and 13, Figure 2), and to reconstruct the following four distances:

1. The medial-lateral distance (MLD) represented by the horizontal distance between the femoral head center and the longitudinal axis of the femur (points 1 and 8, Figure 2).

2. The articulo-trochanteric distance (ATD) according to Edgren (1965; points 5 and 6).

3. The femoral head center-trochanteric distance (CTD) represented by the vertical distance from the

Table 1. Difference between stereoradiography (RSA) and digitized or manual measurements of conventional radiographs. Positive or negative values indicate overestimation or underestimation. Figures are mean (mm) and *2 SD*

		n	Medial-lateral distance (MLD)		Articulo-trochanteric distance (ATD)		Center-trochanteric distance (CTD)		Anterior-posterior distance (APP)	
Total material		345	–1.23	*9.6*	0.88	*5.8*	0.21	*5.4*	–1.65	*6.6*
Interobserver	I	90	0.65	*6.5*	–0.11	*6.6*	–0.74	*5.9*	–1.71	*9.1*
variability[a]	II	90	1.41	*4.9*	–0.49	*6.1*	–1.44	*5.6*	–2.39	*8.7*
Digitized (D) vs	D	116	–0.79[b]	*8.8*	1.18	*6.2*	0.24[b]	*5.8*	–1.79[b]	*6.2*
manual (M)	M	116	–2.15[b]	*10.1*	1.15	*7.1*	1.01[b]	*6.5*	–2.5[b]	*6.7*

[a] I, II First and second observers.
[b] *t*-test, $P < 0.01$.

top of the greater trochanter to the femoral head center (points 1 and 7).

4. The anterior-posterior position (APP) of the femoral head center (Eliasson et al. 1988, Gelberman et al. 1986; points 11 and 14, Figure 2).

The successive changes in these four distances were correlated with the translational displacements obtained by the RSA measurements (medial-lateral, proximal-distal, and anterior-posterior translations of the femoral head center). The diameter of the femoral head on the AP and the lateral view was recorded on each available pair of conventional radiographs.

All the patients were examined at the same time with both conventional radiography and stereoradiography. The examinations were performed the day after the operation, after 1 week, 1 month, 3 months, and thereafter at 3 months intervals up to 2 years or until reoperation due to healing complications. A total of 405 AP and lateral views were available for evaluation. In each patient, changes of the femoral head position between two examinations were calculated, yielding 345 measurements of movements between the first and several subsequent examinations. In 1 of 4 patients (105 pairs of radiographs), corresponding to 90 observations of differences, the measurements on the conventional radiographs were repeated by one additional observer. This observer also manually measured the femoral head center displacements in both planes between the first postoperative and 1–2 subsequent examinations, thus obtaining one or two measurements for each of the patients. All of these measurements were done by drawing lines using a ruler.

Statistics

The Student's *t*-test was used for the statistical analyses.

Results (Table 1)

Total material

Conventional radiographs tended to slightly underestimate the medial-lateral displacement in the total material. One standard deviation of the difference RSA-CR was almost 5 mm. Measurements of proximal-distal displacements displayed the smallest variability. Determination of displacement of the proximal part of the femoral head (change of ATD) was about as accurate as displacement at its center (change of CTD). The standard deviations were less than 3 mm for both types of measurements. Change of APP tended to be slightly underestimated on conventional radiographs.

The standard deviation of the repeated measurements of the femoral head diameter on subsequent CRs in each of the patients and in both projections, intraindividual variation, varied between 0.77–3.24 mm (mean 1.58) and 0.84–4.11 mm (mean 1.77) in the AP and lateral projections, respectively.

Interobserver variability

The CR measurements did not significantly differ between the 2 observers ($P > 0.05$).

Manual measurements

Using a digitizing table did significantly improve accuracy. The mean values and standard deviations (RSA-CR) of the digitized and manual measurements were almost the same for the ATD, whereas the other distances did significantly differ.

Discussion

A few authors have tried to evaluate the accuracy or reproducibility of measurements of movements in femoral neck fractures on conventional radiographs. Charnley et al. (1957) stated that the accuracy of their measurements was ± 0.5 mm, but did not mention how they arrived at that conclusion. Edholm and Thorling (1981) evaluated the reliability of their measurements by comparison between 2 independent observers and calculated the SD for the shortening at ± 0.87 or ± 5.7 mm depending on whether or not the patients had extension defects of their hips. These measurements represented a combination of movements along the cardinal axes. During the healing period, the femoral head displaces laterally, distally, and posteriorly (Ragnarsson et al. 1989, 1991), often in combination with rotation. However, we have not tried to measure rotational movements in the present study, because we found that it was difficult or impossible to quantify rotational movements of the femoral head on conventional radiographs.

Manual measurements include drawings of multiple lines, each associated with a certain error. The setting inexactness using a digitizing table is according to our study smaller. Further, digitized recordings are less time consuming and facilitate data storage and evaluation.

There are few anatomic bony landmarks around the hip joint that can be identified constantly from one examination to another constituting reliable reference points. The center point of the femoral head is easy to identify on both projections, and may be subjected to small errors because of rotations about the axis of the femoral shaft or neck (Lowell 1980). In our study the femoral head center was automatically calculated by the software with the aid of three peripherally defined points approximating the femoral head to a circle in both projections. This simplification seems to be justified as shown by the small intraindividual variation of the femoral head diameter on conventional radiographs.

The medial-lateral displacement of the femoral head center is measured in relation to the longitudinal axis of the femur. In comparison to the RSA values for the displacements along the transverse (X) axis, the MLD values were on an average underestimated by 1.2 mm and displayed a high variability, especially in relation to the usually small translations occurring along the transverse axis during fracture healing (Ragnarsson 1991). This inaccuracy might be explained by the sensitivity of the MLD to internal/external hip rotation and by the oval shape of the femoral shaft (Bell and Brand 1989).

The top of the greater trochanter is influenced by rotation and flexion of the hip (Edholm and Thorngren 1981), and thus might be slightly uncertainly defined if an extension defect develops during the healing period. The top of the femoral head may be placed too distally in case of a flattening/segmental collapse, indicating that the ATD measurements can be misleading over a period of time. By using the distal and intact part of the joint area to reconstruct the outlines of the femoral head, this can partly be compensated for. According to our study, ATD and CTD can be used in clinical materials with about the same accuracy.

The APP measurement in the lateral projection is not quite comparable to displacements along the sagittal (Z) body axis in the RSA evaluation, because the vector representing the APP measurements points backwards and slightly medially when the hip is in the neutral position due to anteversion of the femoral neck. Theoretically, the underestimation of the APP should correlate with the degree of the size of the anteversion. Other factors, such as tube and film cassette positioning, are also important. Finally, it can be difficult to identify the femoral neck in cases of a substantial femoral-neck resorption.

The measurements on conventional radiographs were based on routine radiographs. Although this examination technique aimed at being standardized, patient positioning was not controlled using fluoroscopy, parallelism between the x-ray source, the patient and the film cassettes were not checked in detail, and several examiners were involved. Further, some patients suffering from delayed healing or necrosis developed more or less pronounced contractures of the hip, making a strict standardization difficult or impossible. By using specially designed equipment and few examiners, the accuracy of conventional radiography can probably be further improved. In our study the systematic error could be reduced to less than 2 mm depending on the direction of the displacement. Determination of the proximal-distal displacement was the most accurate. In the individual case, this motion should exceed 5–6 mm (2 SD) to be established with certainty.

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