Cross-Table Lateral Radiographs Accurately Predict Displacement in Valgus-Impacted Femoral Neck Fractures

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**Background:** Femoral neck fractures are classified as nondisplaced (Garden types I and II) or displaced (Garden types III and IV) on the basis of anteroposterior radiographs. Cross-table lateral radiographs are important in the assessment of Garden type-I and II fractures as posterior tilt of the femoral head may influence treatment results. A posterior tilt of >20° has been associated with an increased risk of treatment failure after internal fixation, although the precision of these measurements has not been validated. Therefore, the purpose of the present study was to compare cross-table lateral radiographs with 3-dimensional computed tomographic (3D-CT) reconstructions of Garden type-I and II femoral neck fractures.

**Methods:** Twenty-three patients presenting with Garden type-I and II femoral neck fractures that were verified on anteroposterior radiographs underwent CT scanning immediately after radiographic examination. 3D models of the fractured and uninjured femora were reconstructed from the CT images, and displacement of the 3D models was determined by superimposing the fractured and uninjured femora. We defined a coordinate system with its origin at the center of the uninjured femoral head with the x axis oriented medially; the y axis, posteriorly; and the z axis, cranially. Correlations between lateral radiographs and 3D models were assessed with the Spearman rank coefficient, mean difference, and limits of agreement.

**Results:** Posterior tilt of the femoral head on lateral radiographs was strongly correlated with displacement of the femoral head along the y axis of the 3D models, with a correlation coefficient of 0.86 (p < 0.001). Correlations between the findings on lateral radiographs and displacements along the x or z axis were weak, with coefficients of −0.30 (p = 0.18) and 0.21 (p = 0.34), respectively. The mean difference between displacement on lateral radiographs and displacement along the y axis of the 3D models was smaller, and demonstrated a smaller limits-of-agreement interval, compared with the x or z axis.

**Conclusions:** Our results demonstrated a strong correlation between posterior displacement of the femoral head on lateral radiographs and displacement along the y axis in 3D models of Garden type-I and II femoral neck fractures. This finding indicates that lateral radiographs provide an accurate assessment of posterior tilt.
precisely than radiographs. We recently demonstrated that 3D-CT models are both valid and reliable when used to evaluate linear displacement of the femoral head. 3D models therefore can be used as a reference standard to validate lateral radiographs. On the basis of the findings from an experimental radiographic study with 3D-printed bone models, we hypothesized that the assessment of posterior tilt on lateral radiographs is accurate. The aim of the present study, therefore, was to determine whether lateral radiographs provide an accurate representation of posterior tilt and, thus, are valid for the assessment of Garden type-I and II femoral neck fractures.

**Materials and Methods**

All participants provided informed consent, and the study was approved by the Regional Committees for Medical and Health Research Ethics of Norway (reference 2014/2337) and by the data protection official at Akershus University Hospital (reference 15-048).

**Inclusion**

Between May 15, 2015, and February 16, 2016, the orthopaedic surgeon on call at Akershus University Hospital prospectively assessed anteroposterior and lateral radiographs of the hip that were made for patients who were admitted because of a suspected hip fracture. A consultant radiologist and a consultant orthopaedic surgeon subsequently reviewed the primary assessments. The anteroposterior and lateral radiographs were not standardized with respect to hip rotation during the examinations. Patients with an age of ≥70 years who presented with Garden type-I and II femoral neck fractures were eligible for inclusion in the present study, and patients were given written and verbal information about the purpose and procedures of the study by the surgeon on call before providing consent. Patients with previous injuries to the hip, hip implants, malignant disease, deformities, osteoarthritis (Kellgren and Lawrence grade 2 or higher), or osteomyelitis and those who were unable to provide informed consent were excluded from the study.

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**Fig. 1**

Figs. 1-A and 1-B Coronal (Fig. 1-A) and axial (Fig. 1-B) CT scans of the hip. The red dot depicts the deepest point of the fovea, and the blue sphere indicates the surface of the femoral head. Fig. 1-C 3D model showing the center point (green dot) of the largest cross-sectional area of the lesser trochanter.

**Fig. 2**

Figs. 2-A and 2-B 3D models of the femoral head. Fig. 2-A The orientation of the analytical plane approximates the femoral anteversion angle. Fig. 2-B The origin of the coordinate system is defined at the center of the uninjured femoral head. The x axis crosses the center of the fovea, the y axis is oriented in a posterior direction, and the z axis is oriented cranially.
Patients who were unable to undergo CT scans after the radiographic examinations also were excluded in order to prevent delay of surgical treatment. CT images were compared with the radiographs to account for the possibility of secondary displacement between radiographic examinations and CT scans. Of the 26 eligible patients, 1 patient was excluded because of the occurrence of secondary displacement between the radiographic examination and the CT scan, 1 patient was excluded because of the presence of an orthopaedic implant in the contralateral hip, and 1 patient was excluded because the primary classification was incorrect. The study included 23 patients (16 female and 7 male) with a median age of 83 years (range, 70 to 95 years). Nine fractures were on the left side.

**Generation and Alignment of the 3D Models**

CT examinations were conducted with an iCT 256-slice CT scanner (Philips) set to 120 kVp and 60 mA with 512 × 512-pixel image resolution, 0.78-mm pixel size, 0.45-mm slice increment, and 0.9-mm slice thickness. Images were then exported to Mimics (version 18; Materialise) in DICOM (Digital Imaging and Communications in Medicine) format for further processing. For segmentation, the threshold was set to 1,250 to 2,600 Hounsfield units (HU). The resulting models were sliced at the base of the femoral neck and 5 cm below the lesser trochanter, leaving only the trochanteric region of the proximal part of the femur. A mirrored model of the femoral neck fracture was exported together with the model of the uninjured proximal part of the femur to 3-matic (version 18; Materialise). The models of the femoral neck fracture and the uninjured femur were then superimposed by means of point set registration. To achieve the best possible alignment, the computer software used an iterative closest point (ICP) algorithm to minimize the distance between corresponding points. This process requires manual input of at least 3 corresponding regions on the 2 models, and, to improve the precision of the ICP alignment, we used 7 anatomical landmarks as previously described.4

**Radiographic Assessments**

A consultant orthopaedic surgeon reviewed the CT scans. The center of the fovea was identified by its deepest point, and the center of the femoral head was determined by drawing a sphere tangential to its cortical contour (Figs. 1-A and 1-B). The computer software calculated the cross-sectional area of different segments at the height of the lesser trochanter, and the center of the lesser trochanter was defined by the midpoint of the cross-section with the largest area (Fig. 1-C).

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![Fig. 3](image1.png)

**Fig. 3**

3D model showing the fractured femur (pink) superimposed on the uninjured femur (white). The tan arrow depicts the vector between the centers of the 2 femoral heads, and the purple arrow represents the vector between the 2 foveae.

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![Fig. 4](image2.png)

**Fig. 4**

**Fig. 4-A** Cross-table lateral radiograph illustrating the measurement of posterior tilt as described by Palm et al.2. The intersection between the femoral head and the analytical plane forms a cone with its apex at the center of the femoral head. **Fig. 4-B** Corresponding 3D model. The angle at the base of the cone can be considered equivalent to the 2D posterior tilt angle.
Angular Measurements of Posterior Tilt

Posterior tilt of the femoral head was measured with mdesk software (RSA Medical) according to the method described by Palm et al.² (Fig. 4-A). To calculate a 3D analogue of the posterior tilt angle, we drew a sphere tangential to the femoral head of the fracture model. The resulting intersection between the sphere and the analytical plane formed a cone with its apex at the center of the injured femoral head. The angle at the base of the cone can be considered equivalent to the 2-dimensional (2D) posterior tilt angle (Fig. 4-B).

Outcomes

The primary outcome was the correlation between posterior tilt on lateral radiographs and displacement along the y axis of the corresponding 3D model. We assessed correlations by calculating the Spearman rank correlation coefficient, which, in comparison with the Pearson coefficient, is more robust to skewed data and outliers¹. It is generally accepted that a coefficient of >0.7 indicates a strong linear relationship¹. Secondary outcomes were the correlation between posterior tilt on lateral radiographs and the 3D analogue of the posterior tilt angle and mean differences between displacement on lateral radiographs and displacement along the x, y, and z axes of the 3D models.

Statistical Analysis

Normality was assessed by the inspection of histograms. Limits of agreement define an interval within which 95% of the

Reference Points, Reference Plane, and Coordinate System

The centers of the fovea, femoral head, and lesser trochanter were represented as single points in a 3D space, and together they defined an analytical plane that nearly aligned with the femoral antversion angle (Fig. 2-A). The position of the analytical plane was based on the uninjured femur, and we defined a coordinate system with its origin at the center of the uninjured femoral head. A vector running from the center of the femoral head through the center of the fovea defined the x axis, and the y axis was oriented perpendicular to the plane in a posterior direction. The z axis ran parallel to the plane in a cranial direction (Fig. 2-B). The distance between 2 points was defined by the magnitude of a vector connecting the 2 points (Fig. 3). Femoral head rotation was defined by a vector running from the center of the femoral head to the center of the fovea, and differences in rotation were determined by calculating the absolute angle between corresponding vectors.

### TABLE I Rotations and Displacements of the Femoral Head on Cross-Table Lateral Radiographs and 3D Models of Nondisplaced (Garden Type-I and II) Femoral Neck Fractures *

| Outcome                              | Mean (95% CI) | Range   |
|--------------------------------------|---------------|---------|
| Posterior tilt (deg)                 |               |         |
| On lateral radiographs               | 14.1 (9.8 to 18.3) | −4.7 to 31.0 |
| On 3D models                         | 11.7 (7.8 to 15.5) | −4.0 to 28.2 |
| Rotation of femoral head (deg)       | 18.3 (14.7 to 22.0) | 4.6 to 38.3 |
| Displacement of femoral head (mm)    |               |         |
| Absolute displacement                | 9.6 (7.9 to 11.3) | 3.0 to 15.7 |
| Displacement along x axis            | −0.7 (−3.5 to 2.0) | −12.0 to 8.6 |
| Displacement along y axis            | 5.1 (3.3 to 6.9) | −1.5 to 13.2 |
| Displacement along z axis            | 4.5 (3.4 to 5.6) | 0.6 to 11.0 |

*CI = confidence interval.

### TABLE II Correlations Between Posterior Tilt Assessed by Cross-Table Lateral Radiographs and 3D Models of the Corresponding Nondisplaced (Garden Type-I and II) Femoral Neck Fractures

| Correlation                        | Spearman ρ   | P Value |
|------------------------------------|--------------|---------|
| Mean posterior tilt in 3D models   | 0.86         | <0.001  |
| Rotation of femoral head           | 0.31         | 0.15    |
| Displacement of femoral head       |              |         |
| Absolute displacement              | 0.60         | 0.02    |
| Displacement along the x axis      | −0.30        | 0.18    |
| Displacement along the y axis      | 0.86         | <0.001  |
| Displacement along the z axis      | 0.21         | 0.34    |

### TABLE III Correlations Between Displacement Along the X, Y, and Z Axes in 3D Models of Nondisplaced (Garden Type-I and II) Femoral Neck Fractures

| Correlation                        | Spearman ρ   | P Value |
|------------------------------------|--------------|---------|
| X axis versus y axis               | −0.24        | 0.27    |
| X axis versus z axis               | 0.44         | 0.04    |
| Y axis versus z axis               | 0.35         | 0.11    |

### TABLE IV Mean Difference Between Posterior Displacement on Cross-Table Lateral Radiographs and Displacement on 3D Models of Corresponding Nondisplaced (Garden Type-I and II) Femoral Neck Fractures, with Limits of Agreement *

| Displacement of Femoral Head | Mean Difference | Limits of Agreement |
|------------------------------|----------------|---------------------|
| Absolute displacement        | −18.3          | −50.9 to 14.4       |
| Displacement along x axis    | 24.4           | −36.6 to 85.4       |
| Displacement along y axis    | 0.5            | −22.5 to 23.4       |
| Displacement along z axis    | 2.9            | −31.0 to 36.7       |

*Displacement is divided by the radius of the femoral head and is expressed as a percentage in order to create comparable units of measurements.
differences will fall when 2 measurements are compared. Posterior displacement on lateral radiographs was calculated by measuring the distance from the center of the femoral head to a line bisecting the femoral neck (Fig. 4-A). However, the lateral radiographs were not calibrated, and distances could not be measured directly. To create comparable units of measurement for calculations of mean difference and limits of agreement, we chose to express displacement as a ratio of the distance divided by the femoral head radius. Similarly, for calculations of mean difference and limits of agreement, we also expressed absolute displacement and displacement along the x, y, and z axes of the 3D models as a ratio of the displacement divided by the femoral head radius.

Fig. 5
Scatterplots of posterior tilt on lateral radiographs and displacement of 3D models. The 95% confidence intervals are shown in dark gray, and the 95% prediction intervals are shown in light gray.
head radius. Calculations of limits of agreement were performed with the R package BlandAltmanLeh13.

Femoral offset was determined by measuring the distance from the center of the femoral head to a line bisecting the long axis of the femur on anteroposterior radiographs. Femoral offset and displacement along the x axis were expressed as ratios relative to the femoral head radius, and the correlation between femoral offset and displacement along the x axis of the corresponding 3D model was evaluated with the Spearman rank correlation coefficient.

Prediction intervals, 95% confidence intervals of the mean, and scatterplots were generated in the R package ggplot214. The prediction interval represents an interval that contains the next measured value with 95% certainty. Bland-Altman plots were used to assess agreement between 2 different measurements. All statistical analyses were performed in R (version 3.3.3 for Mac OS X; R Foundation for Statistical Computing)15.

Sample size calculations were based on the hypothesis that the correlation coefficient for displacement on lateral radiographs and displacement on 3D models was >0.7. With a 2-tailed alpha value of 0.5 and with 95% power, the required sample size was 20 patients16.

Results

Mean values for measurements of posterior tilt on posterior lateral radiographs and for rotation and linear displacement of the femoral head on 3D models are given in Table I. Posterior tilt on lateral radiographs correlated strongly with displacement of the femoral head along the y axis and with the 3D analogue of posterior tilt measurements. The correlation between posterior tilt on lateral radiographs and absolute displacement of the femoral head was also significant, but with a lower correlation coefficient (Table II). Correlations between displacements along the x, y, and z axes are given in Table III. There was no correlation between femoral offset on anteroposterior radiographs and displacement along the x axis of the corresponding 3D models, and the correlation coefficient was 0.01 (p = 0.96).

The mean difference in linear displacement was smallest between displacement on lateral radiographs and displacement along the y axis of the 3D models (Table IV). Scatterplots of posterior tilt on lateral radiographs versus displacement of 3D models revealed a similar trend, with a linear correlation between posterior tilt and displacement along the y axis. The resulting prediction and confidence intervals also were smaller for the correlation between posterior tilt and displacement along the y axis as compared with displacement along the x or z axis (Fig. 5). Agreement between displacement on lateral radiographs and displacement of 3D models was also assessed with Bland-Altman plots (Fig. 6).

Discussion

We hypothesized that lateral radiographs accurately assess posterior tilt of the femoral head in patients with Garden type-I and II femoral neck fractures. Our findings demonstrated a strong correlation between posterior tilt on lateral radiographs and posterior displacement on the corresponding 3D models.

Posterior tilt or the presence of valgus impaction was indicated by displacement along the y or z axis, respectively. The mean displacement of the 3D models was largest along the y axis, followed by displacement along the z axis. However, there was no correlation between posterior tilt on lateral radiographs and displacement along the z axis, suggesting that valgus impaction is not necessarily associated with posterior tilt of the femoral head. The radiographs were not standardized with respect to the position of the hip during the examinations, and there was no correlation between femoral offset on the anteroposterior radiograph and displacement along the x axis. This finding suggests that measurements of posterior tilt, as opposed to femoral offset, are more robust to variations in the position of the hip during radiographic examinations.

The trial had several limitations, the most important being sample size. Although the number of patients satisfied the a priori sample power analysis, a larger study may be necessary to account for discrepancies and anatomical variations in the general population. Asymmetrical anatomical variations may influence the accuracy of 3D-CT-based measurements as these measurements...
assessments of posterior tilt on 3D models of the corresponding femoral neck fracture. This strong correlation indicates that lateral radiographs correctly portray displacement. The conflicting reports could, alternatively, be explained by selection bias, as 2 of the 3 studies in question were retrospective cohort studies. Fractures and posterior tilt were furthermore categorized differently, leaving the possibility of assessment bias.

Our results demonstrated a strong correlation between posterior tilt of the femoral head on cross-table lateral radiographs and posterior displacement of the femoral head on 3D models of the corresponding Garden type-I or II femoral neck fracture. Our study confirms that lateral radiographs accurately assess posterior tilt in patients with Garden type-I and II femoral neck fractures.

Cross-Table Lateral Radiographs Predict Displacement in Valgus-Impacted Femoral Neck Fractures

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