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Plain Radiographs Fail to Reflect Femoral Offset in Total Hip Arthroplasty

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ABSTRACT

Successful biomechanical reconstruction is a major goal in total hip arthroplasty (THA). We measured leg length (LL), global (GO) and femoral offset (FO) change on anteroposterior pelvis radiographs and on three-dimensional computed-tomography (3D-CT) with fiducial landmarks after cementless THA on 18 hips of cadaveric specimens. Measurements on radiographs were performed twice by four examiners and showed high interobserver (mean CCC ≥0.79) and intraobserver agreements (mean ICC ≥0.88). Mean differences between radiographic and 3D-CT measurements were 1.0 (SD 2.0) mm for LL, 0.6 (SD 3.6) mm for GO and 1.4 (SD 5.2) mm for FO. 1% of radiographic LL-, 15% of GO- and 35% of FO measurements were outside a tolerance limit of 5 mm. Radiographs seem acceptable for measuring LL/GO change but fail to reflect FO change in THA.

Failure of biomechanical reconstruction in total hip arthroplasty (THA) can lead to gait asymmetry as well as back and knee pain [1,2]. Postoperative leg length (LL) discrepancy is associated with patient dissatisfaction and litigation [3]. Furthermore, a weak reconstruction of global (GO) and femoral offset (FO) correlates to hip stability, impingement, polyethylene wear and is reported to cause trochanteric pain [4–7]. Therefore, preoperative templating and postoperative control of biomechanical restoration are essential in THA. For this purpose, magnification-corrected anteroposterior (AP) radiographs of the pelvis are commonly used in clinical practice due to its ubiquitous availability [8]. Radiographs are reported to be more accurate than clinical techniques using tape or wooden boards [9]. Previous studies emphasize that radiographic measurements on AP radiographs of the pelvis and femur are susceptible to error, since horizontal dimensional parameters are influenced by variations in positioning of the pelvis relative to the plane of the film and the divergence of the x-ray beams [10]. The reliability of these measurements is further reduced by the influence of pelvic tilt and rotation [11]. For that reason, standardized radiographic images of the pelvis are required for a correct assessment of hip biomechanics, although in clinical practice these requirements may be considerably complicated by patient-dependent factors such as obesity and contractures [12]. In contrast, computed-tomography (CT) scans offer the chance for a three-dimensional (3D) view on the pelvis and allow for detailed biomechanical analysis with high accuracy and reproducibility [13,14].

In this experimental study, we aimed to investigate:

(1) the validity of radiographic assessments of LL, GO and FO change on magnification-corrected plain AP pelvis radiographs after THA compared to a three-dimensional (3D) analysis based on CT reconstructions and fiducial landmarks,
(2) the interobserver and intraobserver accuracy of measuring LL, GO and FO change on plain AP radiographs after THA measured twice by four examiners within an eight-week interval and
(3) the correlation between clinical experience and measuring accuracy of LL, GO, FO change on plain AP radiographs.

Materials and Methods

The study was in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. The local ethics committee waived ethics review for cadaver studies. Ten cadaveric specimens were obtained from the Institute of Anatomy. The mean body mass index ranged from 21.5 to 37.2 kg/m^2, mean 26.7 kg/m^2. Out of these twenty hips, two had to be excluded in advance due to prior hip surgery. Eleven female and seven male hips were included in the experiment. All specimens were positioned on a solid spine board (Spencer Rock spine board; Spencer, Parma, Italy) in a comparable supine position. To achieve this, spacer foam blocks were taped to the popliteal fossa, between the medial femoral epicondyles and between the inner malleoli, followed by taping the planar foam block underneath the spine board to ensure preoperatively and postoperatively comparable rotation and tilt of the pelvis as well as similar

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limb rotation, abduction/adduction, and extension/flexion. As reference, a belt containing metal spheres of 9 and 3 mm diameter was fixed around the abdomen. Screws were inserted percutaneously through stab incisions as fiducial landmarks close to the anterior-superior iliac spine, posterior iliac crest, pubic tubercles, greater trochanters, femoral diaphysis, and into the femoral epicondyles. Afterwards, the whole specimen, including the spine board, was wrapped and secured with broad cling film. Then, a plain AP radiograph of the pelvis and a CT scan (Somatom Sensation 16; Siemens, Erlangen, Germany) were taken.

Eighteen THAs were performed in a supine position through a standard anterolateral approach using press-fit acetabular components, cementless hydroxyapatite-coated stems, and metal/ceramic heads (Pinnacle, Corail; DePuy, Warsaw, IN, USA). We aimed to implant the components in a stable position and not to equalize LL and GO/FO discrepancies. In one case, two fiducial landmarks dislocated on the way to CT and it was impossible to obtain measurements according to the protocol. Ultimately, 17 THAs were included in the final analysis. LL, GO and FO change was measured on magnification-corrected AP radiographs of the pelvis using digital planning software (mediCAD; Hectec GmbH, Landshut, Germany). Radiographic magnification was corrected by the size of the prosthetic head on the postoperative radiograph. Then, we measured the distance of the inter-tear-drop line and transferred calibration to preoperative images by using the inter-tear-drop line length. The result was verified with the lateral positioned, standardized metal spheres of the abdominal belt. Femoral length (used as a surrogate for LL) was obtained as published by Murphy drawing a line through the inferior aspects of the teardrops (inter teardrop line or Koehler line) and measuring the distance to the superior margin of the lower trochanter [15]. GO was defined as the distance from the center of rotation of the femoral head to the teardrop along the transteardrop line touching the inferior margins of the teardrop [16]. FO was defined as the distance from the center of rotation of the femoral head to the central axis of the femur [11] (Fig. 1). Differences between the preoperative and postoperative measurements were regarded as true LL, GO and FO change.

Preoperative and postoperative CT scans were reconstructed and analyzed using 3D image processing software (iPlan Stereotaxy 2.6; BrainLAB) which enables reorientation of the pelvis planes. In this context, fiducial landmarks the frontal, sagittal and axial view were identified and the specimens' preoperative and postoperative position was carefully adjusted in order to exclude any rotational errors during the CT measurements (Fig. 2). Leg length was measured as the distance from the superior aspect of the lesser trochanter to a transversal plane through the tagged ASIS. GO was measured as the distance from the pubic tubercle to the femoral axis. For FO, a specific femoral frame was created as described by Sariali et al [17]. FO was measured as the perpendicular distance from the three-dimensional center of the head to the femoral axis (Fig. 3) [11]. The difference of postoperative and preoperative values was regarded as true LL, GO and FO change. Four orthopedic surgeons, two senior surgeons [TR, MWO] and two arthroplasty fellows [RS, MW] performed the measurements on plain AP pelvis radiographs, including a repetition of the procedure after an eight-week interval. The observers were blinded to the 3D-CT and to each other's results, respectively.

Differences between LL, GO and FO change measured on 3D-CT and radiographs were analyzed descriptively, reporting means, standard deviation and 95% confidence intervals (CIs). To account for repeated assessments, the latter statistics were computed by mixed model analysis using a diagonal working correlation matrix. Likewise, method comparison was performed by Bland-Altman plots for repeated measurements. Accuracy of LL, GO and FO measurements was evaluated by using the mean of all eight radiographic measurements made by the four blinded investigators. Intraobserver reliability was tested using intraclass correlation coefficient (ICC); interobserver reliability was tested using concordance correlation coefficient (CCC). Furthermore, potential differences between senior surgeons and arthroplasty fellows were evaluated. Statistical analyses were performed with the help of IBM SPSS Statistics 20 (SPSS Inc., Chicago, IL, USA) and the statistical software package R (The R Foundation for Statistical Computing, Vienna, Austria).

Results

The mean difference between the radiographic and the 3D-CT based measurements was 1.0 (SD 2.0) mm for LL, 0.6 (SD 3.6) mm for GO and 1.4 (SD 5.2) mm for FO. The radiographic change of LL, GO and FO measured by the four observers as well as the 3D-DT values are shown in Table 1. Ninety-five percent of the individual differences (Observer – 3D-CT) were located in an interval of −2.9 to 5.0 mm for change of LL, −6.4 to 7.6 mm for change of GO and −8.8 to 11.5 mm for FO change. One percent (1/68) of the LL change measurements on plain radiographs was outside a tolerance limit of 5 mm compared to the 3D-CT. For OS, 15 % (10/68) of the radiographic GO change measurements and 35 % (24/68) of the FO change measurements on plain radiographs were outside a tolerance limit of 5 mm compared to the 3D-CT. Analyzing the agreement between the 3D-CT and

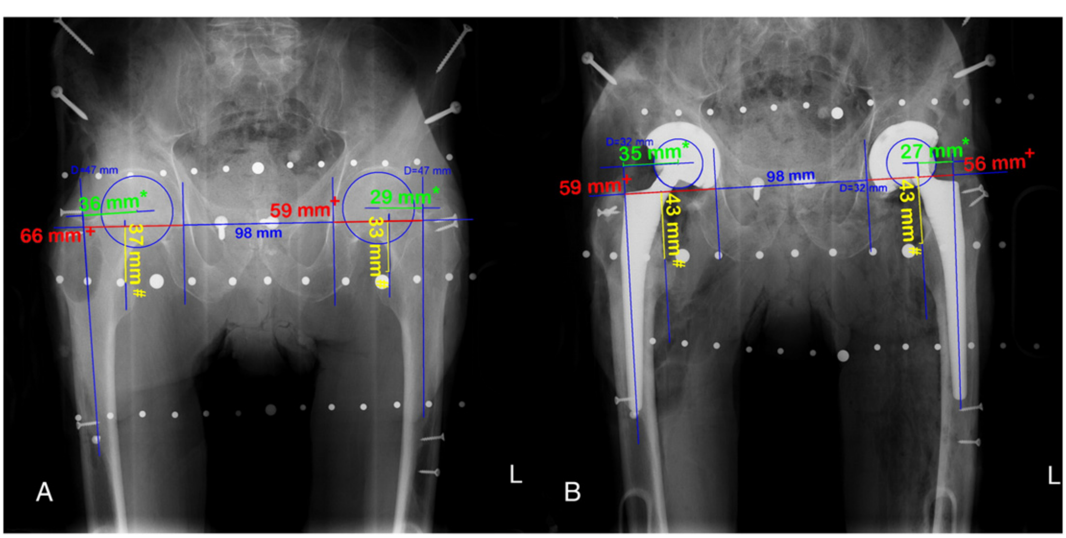

Fig. 1. Change of LL (#), GO (+) and FO (*) were assessed by comparison of magnification corrected preoperative (A) and postoperative (B) AP radiographs of the pelvis.