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Reliability of a New Method for Evaluating Femoral Stem Positioning After Total Hip Arthroplasty Based on Stereoradiographic 3D Reconstruction

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ABSTRACT

The goal of this study was to validate a new method for determining femoral stem positioning based on 3D models derived from the EOS biplanar system. Independents observers measured stem anteversion and femoral offset using CT scan and EOS system of 28 femoral stems implanted in composite femurs. In parallel, the same parameters were measured on biplanar lower limb radiographs acquired from 30 patients who had undergone total hip arthroplasty. CT scanner and biplanar X ray measurements on composite femurs were highly correlated: 0.94 for femoral offset ($P < 0.01$), 0.98 for stem anteversion ($P < 0.01$). The inter and intra observer reproducibility when measuring composite bones was excellent with both imaging modalities as when measuring femoral stem positioning in patients with the biplanar X ray system.

The relationship between implant positioning and the outcome of total hip arthroplasty (THA) has been extensively studied. It is well known that restoring optimal femoral offset improves hip abductor muscle tone [1 3], joint range of motion [1,4] and walking ability[2,5]. It also reduces the risk of dislocation [5,6] and slows down wear [7]. Anteversion of the cup and femoral stem alone and in combination has also become an important aspect to evaluate when looking into the cause of THA dislocations [8 11].

Parameters used to describe implant orientation are mainly in the frontal plane (femoral offset, neck shaft angle, cup angulation) and axial plane (cup and stem version). Frontal plane parameters are typically measured on A/P X rays of the pelvis. However some studies have shown that CT scan images are better suited to these measurements [12,13]. By allowing the slices to be reoriented, CT scan images can get around problems with patient positioning and femoral neck anteversion, which allows frontal plane measurements of each proximal femur to be made. Implant version is typically measured on axial slices from CT scans [14].

A new imaging method, the low dose digital stereoradiography, was recently developed [15,16]. This technique is based on the multiwire proportion chamber for particle detectors, for which G. Charpak won a Nobel Prize in physics. A partnership between a team of biomedical engineers, orthopedic surgeons, and radiologists has transformed it into the low dose system named EOS (EOS Imaging, Paris, France) (Fig. 1).

The system consists of a C shaped vertically traveling arm supporting two image acquisition systems, placed orthogonally, each composed of an x ray tube and a linear detector. The source and detector thus move together, with the beam always horizontal to the patient. The system produces full length, weight bearing images with minimal irradiation [15 18]. Specially designed software included in the workstation allows three dimensional (3D) modeling of the bone envelope and automatic calculation of specific clinical variables. A further extension of this software has been developed to allow to evaluate the positioning of total hip arthroplasty. Measurement of acetabular cup orientation with this method has recently been described and validated [19]. The goal of the current study was to evaluate the precision and reproducibility of this new 3D method for measuring the orientation of femoral stems following total hip arthroplasty. The study was performed in two parts: measurements on composite femurs and measurements on patients who have undergone total hip arthroplasty.

Materials and Methods

Study With Composite Femurs

Twenty eight composite femurs having a medullary canal (Sawbones Inc., Vashon Island, USA) were used in the study. Ten

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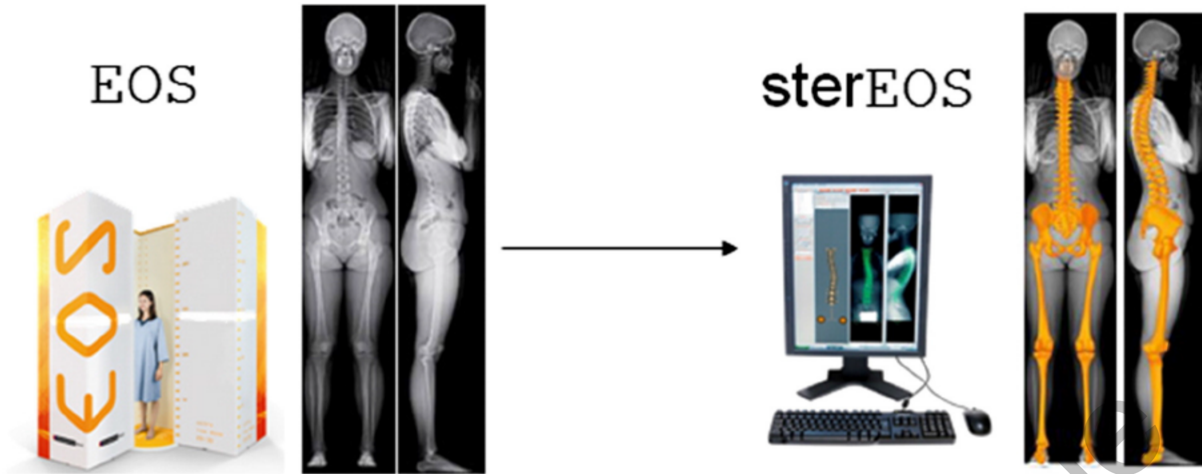

Fig. 1. Low dose system EOS imaging. (A) Takes two simultaneous digital planar radiographs in the standing position with very low dose. (B) Creates a three dimensional bone envelope weight bearing image.

were 35 cm long, 10 were 42 cm long and 8 were 47 cm long. There were 14 right and 14 left femurs. A single surgeon implanted these femurs with 28 different femoral stems (13 Charnley Kerboull type stems, 13 straight stems of other types and 2 anatomical stems). All stems were manually inserted and secured with silicone (Fig. 2A). CT scan images and biplanar radiographs were then taken of each implanted femur (Fig. 2B and C). The CT scan acquisition was performed using a helical 64 slice CT scanner (Brilliance 64, Philips Medical Systems, The Netherlands) to capture 1 mm thick slices of the entire femur. Biplanar radiographs were taken with the EOS system (EOS Imaging, Paris, France) [20,21].

Two other orthopedic surgeons (not involved in the implantation) measured the femoral offset and neck anteversion of the femoral stem twice on each imaging modality. The CT scan measurements were performed using the ORS Visual software (ORS, Montréal, Canada). Femoral offset was measured on reformatted views that allowed the proximal femurs to be viewed in the frontal plane, as recommended in recent published studies [12,13]. Femoral neck anteversion was measured by superimposing axial slices taken from the femoral neck axis to a line tangent to the posterior condyles [14]. For the biplanar acquisition, specialized software (SterEOS, EOS Imaging, Paris, France) was used to obtain a 3D model of the femoral stem. After certain anatomical landmarks were defined manually, 3D models were automatically rendered by contour detection on A/P and lateral images. Femoral offset and neck anteversion of the femoral stem were automatically calculated based on these 3D models.

Study With Patients

After approval from our facility's institutional review board, we carried out a retrospective evaluation of biplanar lower limb radiographs from 30 consecutive patients who had undergone total hip arthroplasty with a ceramic on ceramic implant system (CERAFIT stem and cup, CERAVER, Paris, France). The two independent orthopedic surgeons mentioned above performed 3D measurements of the femoral stems twice on each patient's radiographs to obtain femoral offset and neck anteversion (Fig. 3).

Statistics

The agreement between the CT scan measurements and those of the biplanar X ray system was evaluated in the study on composite femurs. The coefficient of determination (R^2) was used to determine the linear correlation between measurements derived from the two imaging modalities. Student's T test was used to determine if a systematic bias existed between the two measurement methods. The intra observer and inter observer reproducibility for the offset and anteversion measurements was evaluated using the intraclass correlation coefficient (ICC) in the study on composite femurs (CT scan and biplanar X ray system) and the study on patients (biplanar X ray system only).

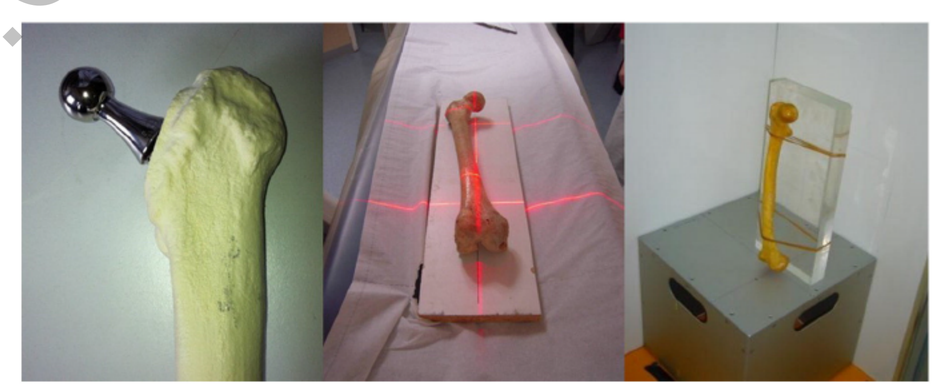

Fig. 2. Study with composite femurs. (A) Femoral stem implanted into composite femur. (B) Femur imaged with CT scan. (C) Femur imaged with EOS biplanar X-ray system.

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Fig. 3. Study with patients. (A) Biplanar radiographs after total hip arthroplasty. (B) Biplanar radiographs with 3D reconstruction.

Results

Study With Composite Femurs

The average offset was 52.11 mm (SD = 7.75 mm) with the CT scan and 52.78 mm (SD = 7.75 mm) with the biplanar X ray system. The measure of the femoral offset between the two methods was statistically significant ($P < 0.05$). The average femoral neck anteversion was 3.82° (SD = 12.49°) with the CT scanner and 4.06° (SD = 12.50°) on the biplanar X ray system without significant difference ($P = 0.3$). Full descriptive data for each modality are given in Table 1. The CT scan and biplanar X ray system measurements were highly correlated: $R^2 = 0.94$ for offset ($P < 0.01$) and $R^2 = 0.98$ for anteversion ($P < 0.01$). The ICC for the intra observer and inter observer reproducibility is shown in Table 2.

Study With Patients

The average femoral offset in this patient population was 43.41 mm (SD = 5.55 mm) and the neck anteversion was 7.78° (SD = 11.46°). The ICC for the intra observer and inter observer reproducibility is shown in Table 3.

Discussion

Precise evaluation of implant positioning after total hip arthroplasty is crucial, particularly when determining the cause of mechanical failures. CT scanning allows for precise measurements of the position of the femoral stem with impressive results (Table 2). A new imaging modality, the biplanar (A/P and lateral) X ray system from EOS, provides a computerized model of the THA that can be used to measure implant positioning in 3D. The goal of the current study was to validate the precision and reproducibility of this new imaging modality for measurements of femoral offset and stem anteversion.

We found a very strong correlation between CT scan measurements and biplanar X ray system measurements. However there was a statistically significant bias for the femoral offset (average of 0.67 mm higher with the biplanar X ray system) and a non significant bias in the anteversion measurement (average of 0.24° higher with the biplanar X ray). We could not identify the reason for these small differences and believe them to be clinically insignificant.

The sub study with composite femur bones allowed us to compare the intra observer and inter observer reproducibility of the measurements between the two modalities. Both modalities had excellent reproducibility, although the biplanar X ray system was slightly better. As one would expect, implant visibility is optimal with composite bones but can be hampered when tissues are superimposed over the bone. The main goal of the sub study on patients was to evaluate the impact of these tissues on the reproducibility of the measurements with the biplanar X ray system. The reproducibility was extremely good with the composite bones, but was also excellent in the patients.

The biplanar X ray system can also be used to measure the offset and neck anteversion of a patient's native femur. The results of the current study can be superimposed with recently published data on femur offset and anteversion [18], which suggests that this technique can be applied during both preoperative planning and postoperative evaluations of implant positioning. Note that use of the biplanar X ray system to evaluate acetabular cup position has already been validated [22].

Although this new imaging modality is promising, it cannot be used with every patient. The patient must stand motionless for the entire acquisition time (about 10 seconds), which could be difficult in cases of postoperative complications or imaging session performed a short time after surgery. Three dimensional models obtained with the biplanar X ray system are very useful for calculating angles. However they are not useful in morphology studies because these models only capture the outer envelope of anatomical structures without showing any of the local details (osteophytes, cysts, osteolysis, etc.).

Table 1
Femoral Offset and Stem Anteversion Measurements Performed on Composite Femur Bones With Each Imaging Modality.

	Femoral Offset (mm)			Femoral Anteversion (°)		
	Biplanar System	CT Scan	*P*	Biplanar System	CT Scan	*P*
Average	52.78	52.11	<0.05	4.06	3.82	0.3
Standard deviation	7.75	7.75		12.50	12.49	
Minimum	41.52	38.12		24.67	-23.80	
Maximum	67.90	70.88		28.30	31.30	

Conclusion

Modeling of hip implants based on A/P and lateral biplanar radiographs with the EOS system is a valid option for the 3D assessment of femoral offset and anteversion following total hip

Table 2
Study With Composite Femurs: Intra-Observer and Inter-Observer Reproducibility (ICC) of Femoral Offset and Stem Anteversion for Each Imaging Modality.

	Femoral Offset		Femoral Anteversion	
	Biplanar System	CT Scan	Biplanar System	CT Scan
Intra-observer	0.999 (0.999–1.000)	0.961 (0.934–0.977)	0.998 (0.995–0.999)	0.998 (0.997–0.999)
Inter-observer	0.998 (0.997–0.999)	0.945 (0.901–0.968)	0.997 (0.993–0.999)	0.992 (0.983–0.996)

Average values with 95% confidence intervals are shown.

Table 3
Study With Patients: Intra-Observer and Inter-Observer Reproducibility (ICC) of the Femoral Offset and Stem Anteversion for Each Imaging Modality.

	Femoral Offset	Femoral Anteversion
	Biplanar X-Ray System	Biplanar X-Ray System
Intra-observer	0.999 (0.999–1.000)	0.998 (0.995–0.999)
Inter-observer	0.967 (0.922–0.990)	0.914 (0.822–0.954)

Average values with 95% confidence intervals are shown.

arthroplasty. As a consequence, this biplanar X ray system can be used during the preoperative planning phase and after surgery to evaluate the quality of an implanted total hip arthroplasty. The EOS system can be used to evaluate implant positioning (femur stem, acetabular cup [22]) and measure leg length differences.

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