




Available online at
 ScienceDirect
www.sciencedirect.com

Elsevier Masson France

www.em-consulte.com/en

**Orthopaedics
& Traumatology**
 Surgery & Research

ORIGINAL ARTICLE

Pelvis and total hip arthroplasty acetabular component orientations in sitting and standing positions: Measurements reproductibility with EOS imaging system versus conventional radiographies

J.Y. Lazennec^{a,*}, M.A. Rousseau^a, A. Rangel^a, M. Gorin^b, C. Belicourt^a,
 A. Brusson^a, Y. Catonné^a

^a Department of orthopaedic and trauma surgery, Pitié-Salpêtrière hospital, 47-83, boulevard de l'Hôpital, 75634 Paris cedex 13, France

^b Department of radiography, Foch hospital, 4, rue Worth, 92151 Suresne, France

Accepted: 7 February 2011

KEYWORDS

EOS measurements;
 Hip prosthesis;
 Total hip arthroplasty;
 Acetabulum;
 Cup;
 Pelvis orientation;
 Anterior pelvic plane

Summary

Introduction: The literature has recently underlined the interest of pelvic and acetabular component orientation measurements in the standing and sitting position. Radiographic follow-up of total hip arthroplasty (THA) is based on standard AP and lateral X-rays. The use of EOS™ 2D imaging system reduces patient's radiation exposure compared to conventional X-rays. However, using this system, the validity and reproducibility of angular measurements, have not been studied yet for the measurement of pelvic and acetabular parameters in patients with THA.

Hypothesis: The EOS™ 2D imaging system offers similar advantages to conventional X-rays in the measurement of pelvic and acetabular orientation parameters which are commonly used.

Patients and method: Five angular parameters characterizing pelvic tilt and acetabular cup orientation were determined using the same digital measurement Imagika™ software based on two series of standard X-rays and EOS™ 2D images acquired in both standing and sitting positions. Radiographs from 50 patients with unilateral THA were measured three times by two observers. Intra- and interobserver reproducibility using each method was independently studied then paired comparison was performed.

Results: The ICC and Spearman rank correlation coefficient demonstrated an excellent EOS/conventional X-ray correlation. According to the parameters, the mean difference between these two imaging modalities ranged from 0.30° to 3.43° ($P < 0.05$). The intra- and interobserver variability ranged from $\pm 2.97^\circ$ to $\pm 6.46^\circ$ using the EOS™ imaging system and from $\pm 4.26^\circ$ to $\pm 10.22^\circ$ using conventional X-rays ($P < 0.05$).

* Corresponding author.

E-mail address: lazennec.jy@wannadoo.fr (J.Y. Lazennec).

Discussion: The EOS™ 2D imaging system may replace conventional X-rays in the assessment and monitoring of pelvic and acetabular cup orientation in THA.

Level of evidence: Level III. Prospective diagnostic study.

© 2011 Elsevier Masson SAS. All rights reserved.

Introduction

Radiographic follow-up of total hip arthroplasties (THA) is based on standard AP and lateral X-rays. Despite its better accuracy [1], CT-scan imaging cannot be routinely performed since it is a costly method, which exposes patients to more radiation. Moreover, CT-scan has to be performed in the supine position whereas the literature has demonstrated the interest of the standing and sitting positions in the measurement of AP and lateral acetabular inclination [2]. Variations in pelvic tilt and anterior pelvic plane orientation (Lewinnek plane) are topical subjects since such variations may significantly modify the prosthetic hip biomechanics [3,4]. Therefore, pelvic parameters commonly measured in spine surgery (pelvic incidence, pelvic version and sacral slope) as well as the Lewinnek plane inclination (helpful in computer-assisted surgery) appear to be relevant elements during the course of THA patients follow-up [5–8].

The EOS™ imaging system provides valuable information in these specific fields since it is capable of simultaneously capturing two orthogonal AP and lateral images thus enabling full-pelvis visualization in both standing and sitting positions [9]. It substantially reduces patient's exposure to X-ray doses compared to conventional X-rays since it combines two simultaneous frontal and lateral acquisitions in a single scan and two gaseous detectors based on the work of Georges Charpak, Nobel Prize in Physics in 1992 [10,11]. The tridimensional EOS analysis allows better understanding of postural adaptation in the standing position [12] but requires reconstruction of volumes. The EOS™ 2D imaging system reduces patient's radiation exposure during the measurement of lumbo-pelvic and acetabular parameters in THA patients.

This work evaluates the reproducibility of angular measurements of lumbo-pelvic and acetabular parameters in order to check the hypothesis according to which the efficiency of this new imaging modality (EOS™ 2D imaging system) is similar to that of the reference method (conventional X-rays) and to determine if the EOS™ 2D system may replace conventional X-rays in this specific indication.

Patients and method

Patients

Fifty patients with unilateral THA were selected since they had no limb length discrepancy and no associated spine pathology. They were prospectively evaluated using a conventional X-ray system and the first generation EOS™ imaging system according to an already described protocol [2] which included AP and lateral pelvic acquisitions in the standing and sitting positions. Standard X-rays and EOS

Table 1 Patient characteristics: mean \pm SD (min.–max.).

Age (years)	60.94 \pm 6.1 (50–73)
Sex ratio (M/F)	24/26
Weight (kg)	79.62 \pm 4.53 (70–87)
Size (m)	1.71 \pm 0.04 (1.64–1.79)
BMI (kg/m ²)	27.08 \pm 0.99 (24.80–29.00)

BMI: body mass index.

images were acquired on the same day. Conventional X-rays were numerized using a Vidar™ Twain 32 scanner and all measurements were performed by means of the Imagika™ software validated in total hip prostheses analyses [13]. Feature characteristics of the patient population are reported in Table 1.

Studied parameters

The measured angular parameters are represented on Fig. 1:

- pelvic incidence [14] (PI) was measured between a line perpendicular to the sacral plate at its midpoint and the line joining this point to the middle of the bicoxo-femoral axis;
- the sacral slope [15] in the standing and sitting position (SSSt/Sit) was defined as the angle subtended by a horizontal reference line and a line tangent to the sacral end plate;
- anterior pelvic plane inclination (Lewinnek plane [16]) in the standing and sitting position (APPISt/Sit) was defined as the angle subtended by a vertical reference line and a line tangent to the anterosuperior iliac spines and the pubic symphysis;
- the acetabular inclination angle in the frontal plane [5] in the standing and sitting position (FAIASt/Sit) was defined as the angle between the cup axis and the horizontal reference line on the AP view;
- the acetabular inclination angle in the sagittal plane [5] in both standing and sitting positions (SAIASt/Sit) was defined as the angle between the cup axis and the horizontal reference line on the lateral view.

All these anatomical parameters were measured on conventional X-rays (Fig. 2) and EOS images (Fig. 3).

Method of analysis

Measurement of angular parameters was conducted by two independent operators (JYL and MG). Three successive measurements were performed for each pelvic parameter by the operator. Measurements performed on conventional X-rays were considered the reference measurements. For

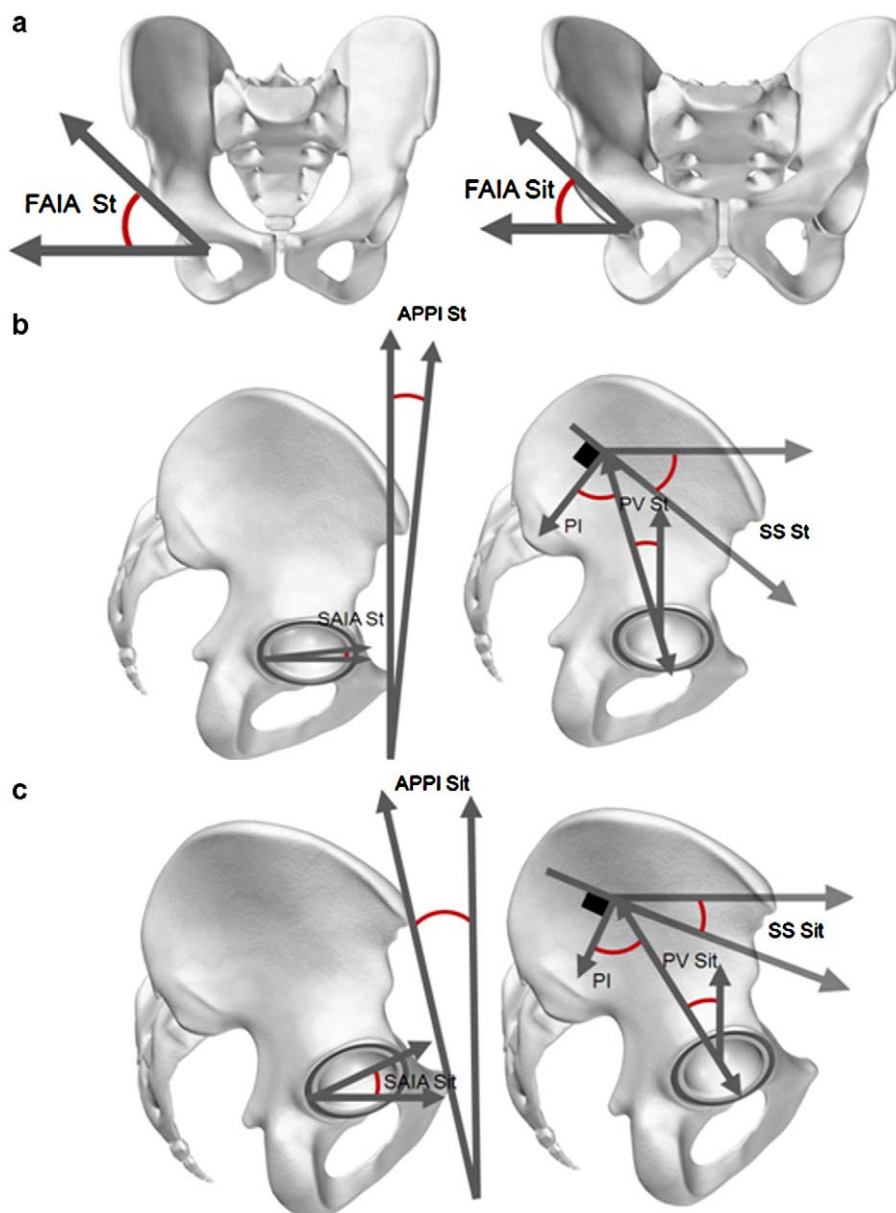


Figure 1 Pelvic parameters and anterior pelvic plane (Lewinnek plane) inclination diagrams. a: AP view in the standing and sitting positions (FAIA/St; FAIA/Sit); b: Sagittal view in the standing position; c: Sagittal view in the sitting position. PI: pelvic incidence, SS/St: Sacral slope standing, SS/Sit: Sacral slope sitting, PV/St: pelvic version standing, PV/Sit: pelvic version sitting, APPI/St: Anterior pelvic plane inclination or Lewinnek plane inclination standing, APPI/Sit: Anterior pelvic plane inclination or Lewinnek plane inclination sitting, FAIA/St: frontal acetabular inclination angle standing, FAIA/Sit: frontal acetabular inclination angle sitting, SAIA/St: sagittal acetabular inclination angle standing, SAIA/Sit: sagittal acetabular inclination angle sitting.

validation of the EOSTM imaging system, the inter- and intraobserver variability of both imaging systems was compared using statistical methods from the literature [17–20].

First, the repeatability (intraobserver) and reproducibility (interobserver) of both imaging system measurements were independently calculated for “conventional X-ray” and “EOS X-ray”. This analysis was inspired by the NF-ISO-5725-2 standard [21]. Such standard provides guidance for the determination of a 95% confidence interval for inter- and/or intraobserver reproducibility. It uses a one-way random-effect model of analysis of variance (ANOVA). The calculated variables were: S_L^2 was the estimated inter-

observer variance, S_W^2 was the estimated intraobserver variance, S_r^2 was the arithmetic mean of S_W^2 representing the estimated repeatability variance, S_R^2 was the estimated reproducibility variance with $S_R^2 = S_L^2 + S_r^2$.

For easier calculation, a new variable was defined for each parameter being the difference between two paired measurements. One-way ANOVA was used to assess the significance of the intra- and interobserver effect within the “conventional X-ray” and the “EOS” group distinctly. Moreover, repeatability and reproducibility were assessed by calculating the inter- and intraobserver Intraclass Correlation Coefficient (ICC) and its 95% confidence interval. The

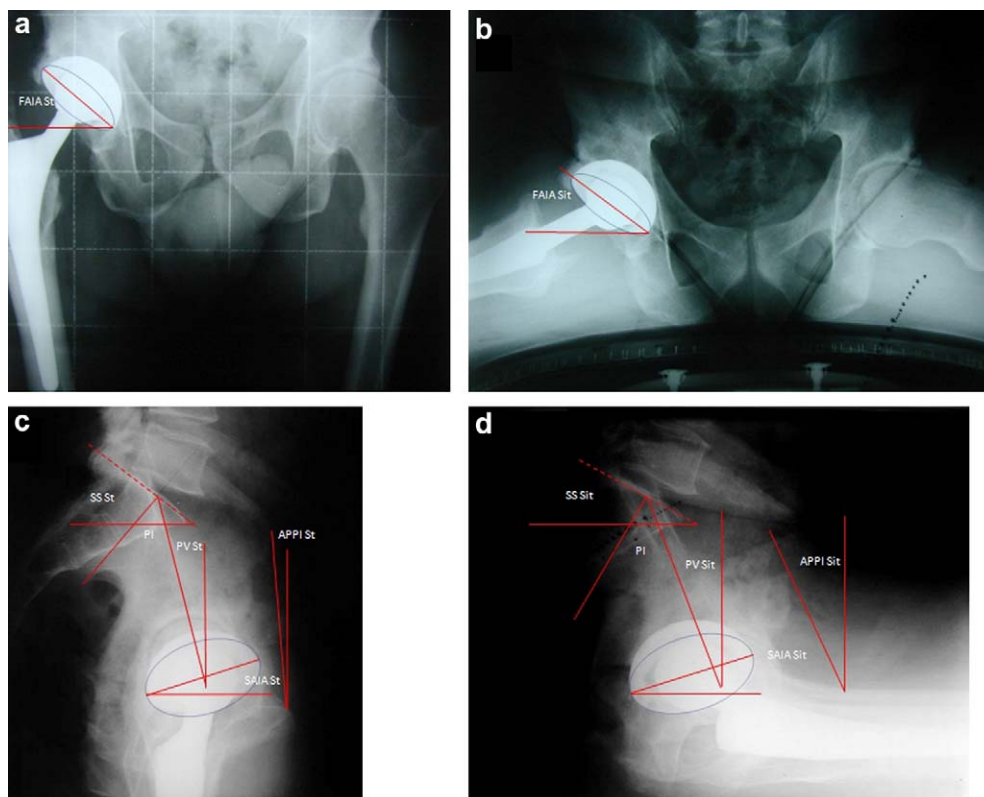


Figure 2 Conventional X-rays. a and c: AP and lateral images in the standing position. b and d: AP and lateral images in the sitting position. PI: pelvic incidence, SS/St: Sacral slope standing, SS/Sit: Sacral slope sitting, PV/St: pelvic version standing, PV/Sit: pelvic version sitting, APPI/St: Anterior pelvic plane (Lewinnek plane) inclination standing, APPI/Sit: Anterior pelvic plane (Lewinnek plane) inclination sitting, FAIA/St: frontal acetabular inclination angle standing, FAIA/Sit: frontal acetabular inclination angle sitting, SAIA/St: sagittal acetabular inclination angle standing, SAIA/Sit: sagittal acetabular inclination angle sitting.

ICC is defined as the ratio between “explained” variance (variance attributable to the cause of variation: observer factor; repetition of measurement) and overall variance (“explained” variance + error variance) [22]. Comparison of repeatability and reproducibility of each parameter was performed using the Fisher-Snedecor test for comparison of variances.

Then, “conventional X-ray” and “EOS X-ray” data collected on the same subjects were directly compared as paired data by means of the protocol used by Rillardon et al. [17] based on one observer and two series of measurements for each imaging modality (conventional and EOS). For each parameter, correlation between data from “conventional” and “EOS” X-rays was calculated using the Spearman’s method and the ICC. The differences between the obtained angular values measured on conventional and EOS images were calculated in order to investigate any significant deviation using a Student’s *t*-test (paired samples).

Data were analyzed using the Medcalc software, version 11.3. Quantitative variables were described using the mean (*M*), the mean difference (*d*), the standard deviation (*SD*), the standard error (*SE*), the Spearman’s rank correlation coefficient (*r*) and the intraclass correlation coefficient (*ICC*) with its confidence interval (*CI* 95%). Normal distribution of the values from the 50 observations was checked for each of the ten angular parameters by means of the Kolmogorov-Smirnov normality test for each series of measurement.

Results

Normal distribution of the values from the 50 observations was confirmed, for each of the ten angular parameters studied, by means of the Kolmogorov-Smirnov normality test applied to each series of measurements. The angular values obtained with each imaging modality are reported in Table 2.

Inter- and intraobserver reproducibility on conventional X-rays

Regarding pelvic parameters, deviations between intra- and interobserver repetitions were not significantly different from zero, thus demonstrating the absence of systematic error for repeatability. The 95% confidence interval corresponding to the random error of each parameter ranged from $\pm 4.26^\circ$ to $\pm 7.83^\circ$.

Regarding acetabular parameters, deviations between intra- and interobserver repetitions were significantly different from zero thus demonstrating a systematic error between the first and the second measurement (ranging from 0.3° to 5.15°) and the first and second observer (ranging from 1.95° to 3.14°). The 95% confidence intervals ranged from 4.79° to 10.22° for cup inclination measurements thus demonstrating dispersion of the measurements.

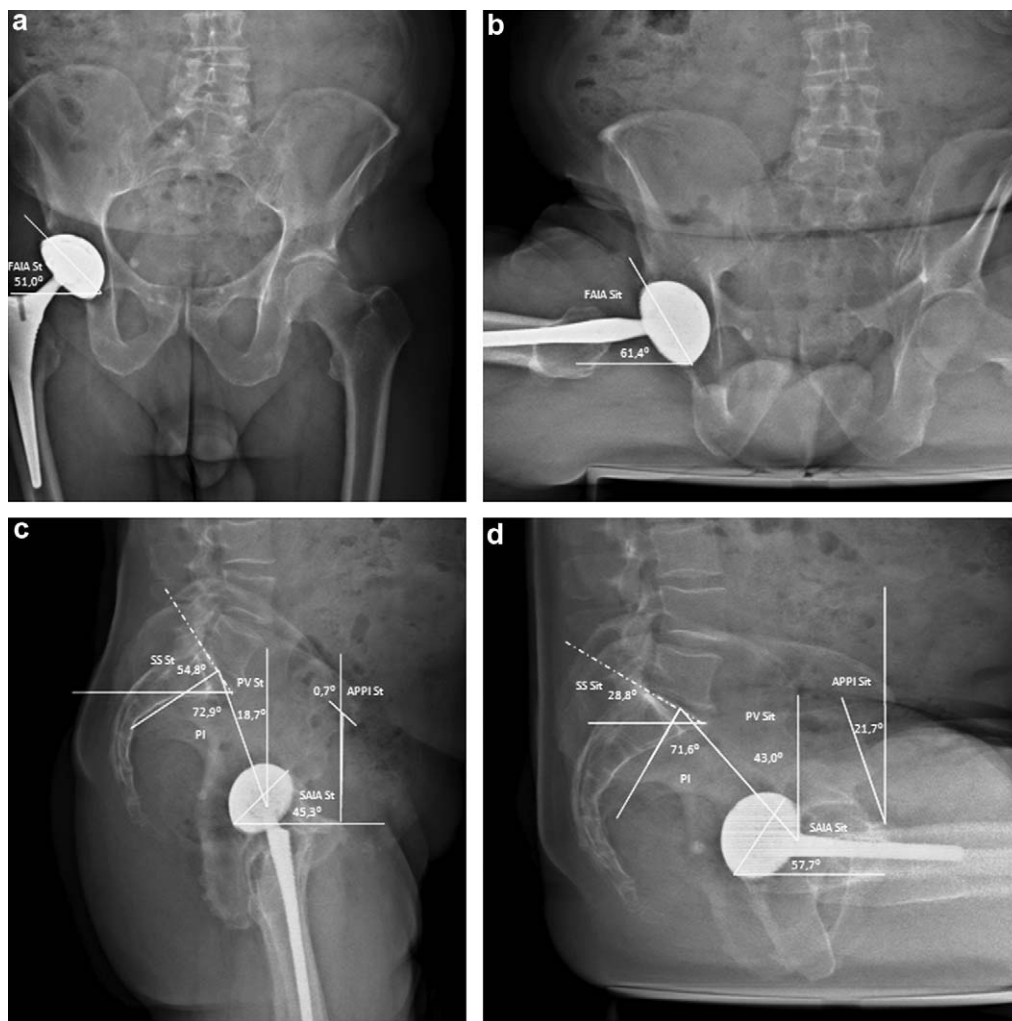


Figure 3 EOS X-rays. a and c: AP and lateral images in the standing position. b and d: AP and lateral images in the sitting position. PI: pelvic incidence, SS/St: Sacral slope standing, SS/Sit: Sacral slope sitting, PV/St: pelvic version standing, PV/Sit: pelvic version sitting, APPI/St: Anterior pelvic plane (Lewinnek plane) inclination standing, APPI/Sit: Anterior pelvic plane (Lewinnek plane) inclination sitting, FAIA/St: frontal acetabular inclination angle standing, FAIA/Sit: frontal acetabular inclination angle sitting, SAIA/St: sagittal acetabular inclination angle standing, SAIA/Sit: sagittal acetabular inclination angle sitting.

Table 2 Results of the nine studied parameters according to the imaging method (mean \pm SD; minimum; maximum). Fifty subjects, two observers, three measurements.

	Conventional X-rays				EOS imaging			
	Mean ($^{\circ}$)	SD	Min	Max	Mean ($^{\circ}$)	SD	Min	Max
Pelvic incidence (PI)	52.9	11.4	25	84	53.9	12.1	29	85
Sacral slope, standing (SS/St)	36.1	7.6	7	59	35.9	7.6	10	55
Sacral slope, sitting (SS/Sit)	23.1	7.3	4	39	24.1	6.8	8	37
Anterior pelvic plane inclination, standing (APPI/St)	2.4	7.3	-18	20	3.3	7.5	-15	20
Anterior pelvic plane inclination, sitting (APPI/Sit)	16.9	9.1	0	44	17.6	7.8	0	42
Frontal acetabular inclination angle, standing (FAIA/St)	52.2	4.9	39	66	53.2	4.8	39	67
Frontal acetabular inclination angle, sitting (FAIA/Sit)	63.0	7.2	46	86	64.3	7.5	50	88
Sagittal acetabular inclination angle, standing (SAIA/St)	47.1	7.1	27	69	47.0	6.7	31	64
Sagittal acetabular inclination angle, sitting (SAIA/Sit)	57.5	9.0	36	84	58.0	9.3	40	84

Table 3 Study of intra- and interobserver variability on conventional X-rays. *d*: mean of deviations, 2 SD: twice the standard deviation (95% confidence interval of deviations), *P* value of the 1-way ANOVA (observer effect for repeatability, measurement repetition effect for reproducibility), ICC: intraclass correlation coefficient, CI 95%: 95% confidence interval of ICC.

	Repeatability					Reproducibility				
	<i>d</i>	2 SD	<i>P</i> value	ICC	CI 95%	<i>d</i>	2 SD	<i>P</i> value	ICC	CI 95%
PI	1.40	4.26	0.400	0.98	0.97/0.99	0.72	4.41	0.598	0.96	0.95/0.98
SS/St	-1.73	6.79	0.284	0.76	0.65/0.84	-1.13	6.95	0.176	0.82	0.75/0.88
SS/Sit	0.46	5.36	0.942	0.86	0.79/0.91	-0.07	5.48	0.698	0.86	0.80/0.91
APPI/St	-0.33	5.39		0.84	0.76/0.90	-1.04	5.55		0.86	0.80/0.90
APPI/Sit	-2.45	7.26	0.180	0.95	0.92/0.97	-4.00	7.83	0.105	0.92	0.89/0.95
FAIA/St	0.30	4.79	0.687	0.78	0.67/0.91	-1.95	5.10	0.001*	0.77	0.68/0.84
FAIA/Sit	-4.54	8.14	<0.001*	0.88	0.82/0.93	-2.60	8.28	0.001*	0.84	0.77/0.90
SAIA/St	-4.46	9.79	0.001*	0.71	0.58/0.81	-2.95	10.22	0.007*	0.69	0.59/0.79
SAIA/Sit	-5.15	8.53	0.001*	0.90	0.85/0.94	-3.14	8.72	0.001*	0.88	0.82/0.92

PI: Pelvic incidence; SS/St: Sacral slope standing; SS/Sit: Sacral slope sitting; APPI/St: Anterior pelvic plane (Lewinnek plane) inclination standing; APPI/Sit: Anterior pelvic plane (Lewinnek plane) inclination sitting; FAIA/St: Frontal acetabular inclination standing; FAIA/Sit: Frontal acetabular inclination angle sitting; SAIA/St: Sagittal acetabular inclination angle standing; SAIA/Sit: Sagittal acetabular inclination angle sitting.

* Significant difference.

Repeatability and reproducibility revealed a tendency towards enlarged distribution for the measurement of the anterior pelvic plane (Lewinnek plane) obtained in the sitting position compared with that obtained in the standing position. The overall metrology (accuracy and precision) results regarding conventional X-rays are reported in Table 3.

Inter- and intraobserver reproducibility on EOS X-rays

Pelvic and acetabular parameters demonstrated a systematic absence of intra- and interobserver error in the sitting and standing positions with a deviation between repetitions which was not significantly different from zero for all parameters, thus demonstrating the absence of systematic error

for repeatability and reproducibility. The 95% confidence interval for each deviation ranged from $\pm 2.97^\circ$ to $\pm 6.46^\circ$ for pelvic parameters and $\pm 3.83^\circ$ to $\pm 6.27^\circ$ for acetabular parameters.

Repeatability and reproducibility revealed a tendency towards enlarged distribution for the measurement of the Lewinnek plane obtained in the sitting position compared with that obtained in the standing position. The overall metrology (accuracy and precision) results regarding EOS X-rays are reported in Table 4.

Comparison of repeatability and reproducibility for both imaging modalities (conventional and EOS)

The results of the Fisher Snedecor tests aim at comparing the above mentioned repeatability and reproducibility

Table 4 Study of intra- and interobserver variability on EOS X-rays. *d*: mean of deviations, 2 SD: twice the standard deviation (95% confidence interval of deviations), *P* value of the 1-way ANOVA (observer effect for repeatability, measurement repetition effect for reproducibility), ICC: intraclass correlation coefficient, CI 95%: 95% confidence interval of ICC.

	Repeatability					Reproducibility				
	<i>d</i>	2 SD	<i>P</i> value	ICC	CI 95%	<i>d</i>	2 SD	<i>P</i> value	ICC	CI 95%
PI	-0.05	4.05	0.951	0.96	0.95/0.98	-0.07	4.12	0.981	0.96	0.95/0.98
SS/St	-0.51	3.36	0.741	0.95	0.92/0.97	-0.24	3.38	0.806	0.95	0.93/0.97
SS/Sit	0.56	3.32	0.712	0.94	0.91/0.96	-0.22	3.42	0.722	0.94	0.91/0.96
APPI/St	-0.22	2.97	0.960	0.95	0.92/0.97	-0.16	3.01	0.856	0.95	0.93/0.97
APPI/Sit	-1.47	5.88	0.383	0.95	0.92/0.97	-3.25	6.46	0.098	0.92	0.88/0.94
FAIA/St	1.36	6.17	0.266	0.66	0.52/0.77	-1.21	6.27	0.072	0.69	0.59/0.78
FAIA/Sit	-0.12	4.31	0.856	0.93	0.90/0.96	-0.84	4.38	0.388	0.92	0.88/0.94
SAIA/St	-0.84	4.34	0.869	0.91	0.87/0.95	-0.31	4.43	0.680	0.90	0.86/0.94
SAIA/Sit	-0.84	3.83	0.871	0.96	0.94/0.97	-0.39	3.89	0.714	0.96	0.94/0.97

PI: Pelvic incidence; SS/St: Sacral slope standing; SS/Sit: Sacral slope sitting; APPI/St: Anterior pelvic plane (Lewinnek plane) inclination standing; APPI/Sit: Anterior pelvic plane (Lewinnek plane) inclination sitting; FAIA/St: Frontal acetabular inclination standing; FAIA/Sit: Frontal acetabular inclination angle, sitting; SAIA/St: Sagittal acetabular inclination angle standing, SAIA/Sit: Sagittal acetabular inclination angle sitting.

Table 5 Comparisons according to the selected X-ray method (50 subjects, one observer, two series of measurements). *r*: Spearman's rank correlation coefficient, ICC: intraclass correlation coefficient, CI 95%: 95% confidence interval of ICC, *d*: mean of deviations (conventional –EOS), SE: standard error of deviations, SD: standard deviation, \pm IC 95%: 95% confidence interval of deviations, *P* value: Paired Student *t*-test.

	<i>r</i>	ICC	CI 95%	<i>d</i>	SE	SD	\pm CI 95%	<i>P</i> value
PI	0.97	0.98	0.97/0.99	–0.30	0.30	2.15	\pm 4.21	0.33
SS/St	0.92	0.94	0.90/0.96	–0.62	0.36	2.56	\pm 5.02	0.09
SS/Sit	0.97	0.98	0.96/0.99	–0.95	0.20	1.42	\pm 2.78	< 0.001*
APPI/St	0.92	0.95	0.91/0.97	–1.47	0.30	2.12	\pm 4.16	< 0.001*
APPI/Sit	0.92	0.93	0.85/0.97	–2.04	0.48	3.39	\pm 6.65	0.01*
FAIA/St	0.90	0.90	0.84/0.94	–1.77	0.28	2.00	\pm 3.92	< 0.001*
FAIA/Sit	0.85	0.92	0.86/0.95	–3.43	0.42	2.94	\pm 5.76	< 0.001*
SAIA/St	0.90	0.92	0.87/0.96	–2.39	0.38	2.66	\pm 5.22	< 0.001*
SAIA/Sit	0.94	0.94	0.90/0.97	–3.16	0.44	3.10	\pm 6.08	< 0.001*

PI: Pelvic incidence; SS/St: Sacral slope standing; SS/Sit: Sacral slope sitting; APPI/St: Anterior pelvic plane (Lewinnek plane) inclination standing; APPI/Sit: Anterior pelvic plane (Lewinnek plane) inclination sitting; FAIA/St: Frontal acetabular inclination angle standing; FAIA/Sit: Frontal acetabular inclination angle sitting; SAIA/St: Sagittal acetabular inclination angle standing; SAIA/Sit: Sagittal acetabular inclination angle sitting; * significant difference.

variances. Except for pelvic incidence, all tests were significant ($P < 0.001$), demonstrating a reduced variance with EOS X-rays.

Direct-paired comparisons of angle measurements obtained with the two imaging modalities (conventional and EOS)

Correlation between the two radiographic systems was excellent for all parameters (Spearman's coefficient ranging from 0.82 to 0.97, ICC 0.90 to 0.98). However, direct-paired comparison using the Student's *t*-test demonstrated a significant difference between the measured values for all parameters except for pelvic incidence and sacral slope in the standing position. This significant difference was 1–2° for pelvic parameters and 2–3° for acetabular parameters. These whole results are reported in Table 5.

Discussion

Through this study, we could determine the degree of uncertainty for pelvic and acetabular parameter measurements with conventional and EOS X-rays using the same measurement software. Direct-paired comparison revealed a good correlation between these two imaging systems in both standing and sitting positions. Study of the reproducibility demonstrated a better accuracy of the EOS system.

However, this study does not allow us to assess the relevancy of the EOS system in the evaluation of other monitoring elements such as osteolysis, granulomas and loosening. On the other hand, the high quality images did provide a more accurate evaluation of angular measurements.

The uncertainty of radiographic parameter measurements has already been studied for manual and computer-assisted measurement of cervical and lumbo-pelvic spine parameters [23–25]: the results are comparable to those reported in our study with conventional X-rays. However, no study has ever been published in the literature about the

EOS system. Moreover, our study reports original data since it deals with acetabular parameter measurements which repeatability and reproducibility have never been reported up to now.

The first part of the study demonstrates a higher variance with conventional X-rays than with the EOS system. Besides the image resolution (Figs. 2 and 3), the difference in accuracy might be related to the method of acquisition: conventional X-ray systems project the information on the patient's reference plane by means of a conical dimensional effect. The image quality is thus altered from the centre towards the edges thus leading to progressively increasing errors for the areas located away from the centre. The EOS slot-scanning X-rays are always aligned with the detectors thus enhancing image contrast performance. Due to the fan-beam geometry, the only alteration encountered during scanning is located along the horizontal axis. However, distortion of this cylindrical image projection is corrected by a new digital graduation executed by the visualization interface of the system. This image is reconstructed as if it had been acquired in the patient's reference plane by limiting the alteration of the patient's thickness instead of the whole source to detector distance. Therefore, the EOS imaging system provides homogeneity on the whole radiograph. In the study of Deschène et al. [11], the overall image quality was considered equivalent or even better with the EOS system in 97.2% of the cases during follow-up of children operated on for scoliosis.

In the second part of our study, the measured values were significantly different between the two imaging systems, however, these differences were lower than the uncertainty estimated in the first part of the study. Such significance thus appears purely statistical and does not correspond to a systematic error in practice. However, variable distribution (95% confidence interval of deviations) demonstrated a distribution reduced by half with EOS X-rays compared to conventional X-rays. It thus appears that for mean corroborating measurements, the EOS demonstrates a better reliability regarding individual measurements.

Conclusion

To conclude, the EOS 2D imaging system appears as an interesting alternative to conventional X-rays in the study of pelvic and acetabular parameters: the EOS imaging system reduces radiation exposure compared to conventional X-rays according to the data published in the literature regarding spine and pelvis; despite image acquisition by scanning, the time required for simultaneous acquisition of front and lateral images is similar to the overall time required for acquisition of two conventional radiographs. Finally, according to our study, the image accuracy achieved using the EOS 2D imaging system is at least similar to that obtained with conventional X-rays and may replace standard radiographs in the assessment of pelvic parameters as well as frontal and sagittal orientation of THA acetabular cups. Moreover, EOS X-rays and possible 3D reconstruction provide a full body image of the patient in the standing and sitting positions which allows a new approach to postural abnormalities involving both the spine and the subpelvic area while the literature has recently underlined the interest of pelvic tilt and acetabular orientation measurements in the standing and sitting positions. The EOS imaging is not currently accessible to the whole population due to the limited number of equipments available and its cost has not been evaluated yet.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

- [1] Wan Z, Malik A, Jaramaz B, Chao L, Dorr LD. Imaging and navigation measurement of acetabular component position in THA. *Clin Orthop Relat Res* 2009;467:32–42.
- [2] Lazennec JY, Charlot N, Gorin M, Roger B, Arafati N, Bissery A, et al. Hip-spine relationship: a radio-anatomical study for optimization in acetabular cup positioning. *Surg Radiol Anat* 2004;26:136–44.
- [3] Babisch JW, Layher F, Amiot LP. The rationale for tilt-adjusted acetabular cup navigation. *J Bone Joint Surg Am* 2008;90:357–65.
- [4] Kalteis TA, Handel M, Herbst B, Grifka J, Renkawitz T. In vitro investigation of the influence of pelvic tilt on acetabular cup alignment. *J Arthroplasty* 2009;24:152–7.
- [5] Lazennec JY, Riwan A, Gravez F, Rousseau MA, Mora N, Gorin M, et al. Hip-spine relationships: application to total hip arthroplasty. *Hip Int* 2007;17(Suppl 5):S91–104.
- [6] Legaye J. Influence of the sagittal balance of the spine on the anterior pelvic plane and on the acetabular orientation. *Int Orthop* 2009;33:1695–700.
- [7] Rousseau MA, Lazennec JY, Boyer P, Mora N, Gorin M, Catonne Y. Optimization of total hip arthroplasty implantation: is the anterior pelvic plane concept valid? *J Arthroplasty* 2009;24:22–6.
- [8] Philippot R, Wegrzyn J, Farizon F, Fessy MH. Pelvic balance in sagittal and Lewinnek reference planes in the standing, supine and sitting positions. *Orthop Traumatol Surg Res* 2009;95:70–6.
- [9] Dubousset J, Charpak G, Skalli W, Kalifa G, Lazennec JY. EOS stereo-radiography system: whole-body simultaneous antero-posterior and lateral radiographs with very low radiation dose. *Rev Chir Orthop* 2007;93:141–3.
- [10] Kalifa G, Charpak Y, Maccia C, et al. Evaluation of a new low-dose digital X-ray device: first dosimetric and clinical results in children. *Pediatr Radiol* 1998;28:557–61.
- [11] Deschenes S, Charron G, Beaudoin G, et al. Diagnostic imaging of spinal deformities: reducing patients radiation dose with a new slot-scanning X-ray imager. *Spine* 2010;35:989–94 [Phila Pa 1976].
- [12] Lazennec JY, Rangel A, Baudoine A, Skalli W, Catonne Y, Rousseau MA. The EOS imaging system for understanding a patellofemoral disorder following THR. *Orthop Traumatol Surg Res* 2011;97 [In press].
- [13] Girard J, Touraine D, Soenen M, Massin P, Laffargue P, Migaud H. Measurement of head penetration on digitalized radiographs: reproducibility and accuracy. *Rev Chir Orthop* 2005;91:137–42.
- [14] Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J* 1998;7:99–103.
- [15] Legaye J, Duval-Beaupere G. Sagittal plane alignment of the spine and gravity: a radiological and clinical evaluation. *Acta Orthop Belg* 2005;71:213–20.
- [16] Lewinnek GE, Lewis JL, Tarr R, Compere CL, Zimmerman JR. Dislocations after total hip-replacement arthroplasties. *J Bone Joint Surg (Am)* 1978;60:217–20.
- [17] Rillardon L, Levassor N, Guigui P, Wodecki P, Cardinne L, Templier A, et al. Validation of a tool to measure pelvic and spinal parameters of sagittal balance. *Rev Chir Orthop* 2003;89:218–27.
- [18] Fermanian J. Validation of assessment scales in physical medicine and rehabilitation: how are psychometric properties determined? *Ann Readapt Med Phys* 2005;48:281–7.
- [19] Fuhrman C, Chouaid C. Concordance between two variables: numerical approaches (qualitative observations – the kappa coefficient – quantitative measures. *Rev Mal Respir* 2004;21:123–5.
- [20] Journois D. Concordance between two variables: graphical approach (Bland and Altman's method). *Rev Mal Respir* 2004;21:127–30.
- [21] NF-ISO-5725-2 I-. Application de la statistique – Exactitude (justesse et fidélité) des résultats et méthodes de mesure – Partie 2: méthode de base pour la détermination de la répétabilité et de la reproductibilité d'une méthode de mesure normalisée, 1994.
- [22] Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull* 1979;86:420–8.
- [23] Champain S, Benchikh K, Nogier A, Mazel C, Guise JD, Skalli W. Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. *Eur Spine J* 2006;15:982–91.
- [24] Blondel B, Parratte S, Tropiano P, Pauly V, Aubaniac JM, Argenson JN. Pelvic tilt measurement before and after total hip arthroplasty. *Orthop Traumatol Surg Res* 2009;95:568–72.
- [25] Dimar 2nd JR, Carreon LY, Labelle H, Djurasovic M, Weidenbaum M, Brown C, et al. Intra- and interobserver reliability of determining radiographic sagittal parameters of the spine and pelvis using a manual and a computer-assisted methods. *Eur Spine J* 2008;17:1373–9.