BJR

https://doi.org/10.1259/bjr.20210047

Received: 06 January 2021 | Revised: 22 April 2021 | Accepted: 26 April 2021

Cite this article as:
Flintham K, Alzyoud K, England A, Hogg P, Snaith B. Comparing the supine and erect pelvis radiographic examinations: an evaluation of anatomy, image quality and radiation dose. *Br J Radiol* 2021; **94**: 20210047.

FULL PAPER

Comparing the supine and erect pelvis radiographic examinations: an evaluation of anatomy, image quality and radiation dose

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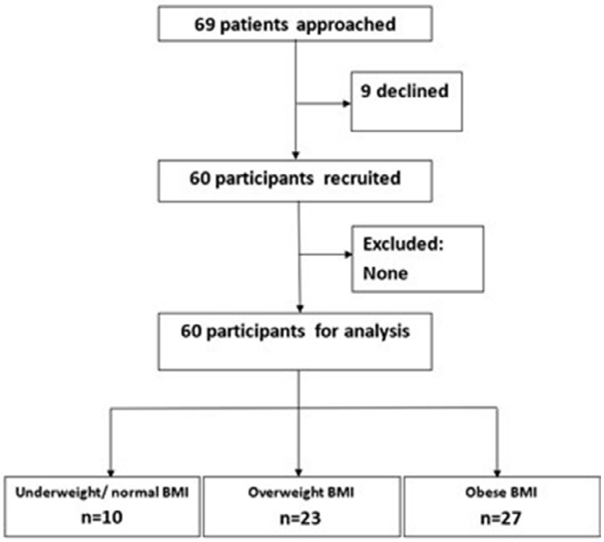
Objectives: Pelvis radiographs are usually acquired supine despite standing imaging reflecting functional anatomy. We compared the supine and erect radiographic examinations for anatomical features, radiation dose and image quality.
Methods: 60 patients underwent pelvis radiography in both supine and erect positions at the same examination appointment. Measures of body mass index and sagittal diameter were obtained. Images were evaluated using visual grading analysis and pelvic tilt was compared. Dose–area product values were recorded and inputted into the CalDose_X software to estimate effective dose (ED). The CalDose_X software allowed comparisons using data from the erect and supine sex-specific phantoms (MAX06 & FAX06).
Results: Patient sagittal diameter was greater on standing with an average 20.6% increase at the iliac crest (median 30.0, interquartile range [26.0 to 34.0] cm), in comparison to the supine position [24.0 (22.3 to 28.0) cm; $p < 0.001$]. 57 (95%) patients had posterior pelvic tilt on weight-bearing. Erect image quality was significantly decreased with median image quality scores of 78% (69 to 85) compared to 87% for the supine position [81 to 91] ($p < 0.001$). In the erect position, the ED was 47% higher [0.17 (0.13 to 0.33) mSv *vs* 0.12 (0.08 to 0.18) mSv ($p < 0.001$)], influenced by the increased sagittal diameter. 42 (70%) patients preferred the standing examination.
Conclusion: Patient diameter and pelvic tilt were altered on weightbearing. Erect images demonstrated an overall decrease in image quality with a higher radiation dose. Optimal acquisition parameters are required for erect pelvis radiography as the supine technique is not directly transferable.

BACKGROUND

In the assessment of hip pathology, radiographs are a critical tool. They are often the primary investigation for structural abnormalities such as dysplasia or femoroacetabular impingement (FAI) and in the monitoring of degenerative disease and arthroplasties.[1,2] In the United Kingdom (UK), the anteroposterior (AP) pelvis projection is usually acquired supine,[3] although there is a lack of standardisation in image acquisition parameters.[3,4] Some authors have concluded that the standing position offers better visualisation of functional anatomy,[5–9] however, the quality of the images has been questioned.[1,10]

Supine radiographs may not accurately represent actual anatomy and may result in inaccurate acetabular measures[11] and inappropriate assessment of the version of acetabular arthroplasty components.[12–14] Previous research has focused on the utility of the erect (weightbearing) pelvis using diagnostic or clinical outcomes.[25–28] The effect of patient position on image quality and/or radiation dose has been considered for other truncal radiographic examinations, such as the lumbar spine and abdomen,[15–20] but little regard has been given to the impact of position on the pelvic region acknowledged changes in organ location and abdominal diameter.[21–24]

Figure 1. Trial recruitment flowchart. BMI, body mass index.



With an absence of evidence-based acquisition parameters in the weight-bearing position, this study aimed to compare supine and erect pelvic radiographs in terms of anatomical features, radiation dose and image quality.

METHODS

Study design

This prospective single-centre study was performed at a multisite NHS Trust in northern England. The study (ISRCTN 10988267) was approved by an NHS Ethics Committee (17/YH/0363) and the Health Research Authority prior to commencement. Adult patients (≥18 years) referred for a hip or pelvis radiograph from their general practitioner or an outpatient clinic were screened for study inclusion. Exclusion criteria were: (1) inability to weight bear, (2) pregnancy, (3) trauma, hip or knee surgery, pelvis radiography or pelvic radiotherapy in the preceding 6 months. 60 patients agreed to participate (Figure 1) and informed written consent was obtained.

Figure 1 Study recruitment.

Imaging protocol

Images were obtained using an Evolution DRX-1 digital radiography system (Carestream Health Inc, Rochester, NY). The decision to perform the supine or erect projection first was randomly assigned and patient preference was sought at the end of the whole examination. All patients had the two examinations performed using 90 kVp with both upper-outer automatic exposure control (AEC) chambers selected. A small cohort of radiographers (n = 3) undertook all examinations following training to ensure consistency.

Patient weight and height were measured at the time of the examination to enable calculation of the body mass index (BMI). Before each exposure, the source to skin distance for each patient was measured at the level of lower costal margin, iliac crest and greater trochanter using the in-built tape measure in the X-ray tube. This value was then subtracted from the source-to-image distance (SID) and was used to determine the sagittal diameter (AP patient thickness) for each position.

For all supine radiographs, a 140 cm SID was used. A decision to switch from 140 cm (n = 37) to 180 cm (n = 23) SID for the erect position was undertaken mid-study in an attempt to manage perceived increased dose. This was in line with the study protocol and was based on the work of several authors.[17,20] For all supine X-ray images, an 80 lp/cm (12:1), 110 cm focussed anti scatter radiation grid was used. Erect images were acquired at 140 cm SID with a 80 lp/cm (12:1) focussed grid (140 cm) or at 180 cm with an 80 lp/cm (15:1) grid focused at 180 cm.

The supine examination was performed as typically described in the literature.[2,29,30] The central ray was positioned in the midline 5 cm above the level of the greater trochanter unless a hip replacement was *in situ* in which case the centring was at the level of the greater trochanter. For the erect position, the patient was asked to stand against the vertical Bucky, with arms placed across the chest, a position validated during an earlier study.[31] For both projections, the legs were internally rotated by 15° to 20° to allow for clearer visualisation of the femoral neck.

Image assessment

Change in sagittal tilt of the pelvis between the supine and erect positions was assessed using the distance between the superior border of the pubic symphysis and the sacrococcygeal joint (PSSC) in line with previous studies.[6–9] A negative value indicated that the SC joint was projected below the level of the PS. A decrease in the PSSC distance between the supine and erect positions indicated posterior tilt of the pelvis on standing and vice versa. The impact of gender and BMI on pelvic tilt (PT) using the PSSC value was considered.

Image quality was assessed by four reviewers with between 10 and 32 years' radiographic experience (two clinical radiographers and two reporting radiographers). All 120 images were assessed using visual grading analysis (VGA) on a 5-point Likert scale (Box 1), similar to Mraity and colleagues.[32] For each criterion, a minimum possible score was 1 and the maximum possible score was 5 (1, strongly disagree; 2, disagree; 3, neither agree / disagree; 4, agree; 5, strongly agree). Scores were calculated such that each image could receive a minimum score of 22 and a maximum of 110. For the two criteria that were negatively worded, the scoring was reversed. When anatomy was absent from the image (*e.g.* iliac crests on patients with hip prostheses), then the number of scale items were reduced accordingly, and the minimum and maximum possible scores recalculated for the individual image. The percentage of the maximum permissible scores across all images were calculated for each of the four observers, and an average total score determined. Percentage maximum permissible scores were also calculated for individual anatomical points.

Box 1: Criteria used for the absolute VGA, adapted from Mraity et al32

Item	Descriptor
1	The right iliac crest is adequately visualized
2	The right sacroiliac joint is adequately visualized
3	The right hip joint is adequately visualized
4	The right femoral neck is adequately visualized
5	The right greater trochanter is adequately visualized
6	The right lesser trochanter is adequately visualized
7	The right proximal femur is adequately visualized
8*	The sacrum and foramina are **NOT** adequately visualized
9*	The pubic and ischial rami are **NOT** adequately visualized
10	The left iliac crest is adequately visualized
11	The left sacroiliac joint is adequately visualized
12	The left hip joint is adequately visualized
13	The left greater trochanter is adequately visualized
14	The left lesser trochanter is adequately visualized
15	The left femoral neck is adequately visualized
16	The left proximal femur is visualized adequately
17	There is appropriate differentiation between soft tissues
18	The exposure factors used for this image are correct
19	The image is sufficient for diagnostic purposes
20	The medulla and cortex of the pelvis are adequately demonstrated
21	Both acetabula are visualised clearly
22	Fine bony detail is sufficiently demonstrated
* scores for these criteria were reversed.	

Dosimetry

The dose–area product (DAP) and post-exposure tube current–time product (mAs) for each patient was recorded in both positions. DAP values were entered into CalDose_X Version 5[34] to facilitate estimates of effective dose (ED). Unlike other dosimetry software packages, CalDose_X includes supine and erect phantom datasets (MAX06 and FAX06).[35] It does not give the option to define the radiation field, patient weight and height, it did allow the selection of an anteroposterior pelvis projection and both the position of the patient (standing and supine) and the patient's sex. As advised by Kramer et al,[34] according to the definition in ICRP 103,[36] the ED can be estimated using CalDose_X by determining the arithmetic mean of the two sex-specific weighted absorbed doses outputted from the software.

Statistical analysis

SPSS (IBM Inc, Armonk, NY) was used for statistical analysis. The Shapiro–Wilk test was used to check the distribution of the data. Mean values and standard deviations were used for data which were normally distributed with median values and interquartile ranges reported for non-parametric data. The reliability between the four observers was evaluated using intraclass correlation coefficient (ICC). The Wilcoxon test was used to evaluate differences between erect and supine positions and the Kruskal–Wallis test for differences between erect and supine positions for different BMI groups[37] (normal [18.5–24.99], overweight [≥25–29.99] and obese [≥30]). Finally, the Spearman rank test was used to examine the patient diameter in different positions. p values of <0.05 were considered statistically significant.

Table 1. Patient demographics

		Mean ± SD/Median (IQR)			
	n	Age, years	Weight, kg	Height, m	BMI, kg/m^2
Male	22	64.1 ± 13.9	96.6 ± 18.2	1.7 ± 0.1	31.6 ± 4.5
Female	38	64.7 ± 11.2	70 (64.2–83.5)	1.6 ± 0.1	27.6 (24.9–32.9)
Total	60	64.5 ± 12.2	80.5 (67.9–98.4)	1.7 ± 0.1	29.4 (25.2–33.4)

IQR, interquartile range; SD, standard deviation.

Note. Data for male patients were normally distributed and is presented as mean ± SD. For female participants data were not normally distributed, hence median and IQR have been reported. When the data are combined they have been treated as not normally distributed.

RESULTS

Study participants

A total of 60 participants (Table 1) and their paired radiographs were included in the analysis. Most examinations were undertaken for the investigation of hip pain or osteoarthritis ($n = 47$; 78.3%). 15 of the patients (25.0%) had a single hip arthroplasty, with four (6.7%) being bilateral (all with surgery greater than 6 months prior). Only five patients preferred the supine position, with the majority favouring the standing examination ($n = 42/60$; 70%), the remaining 13 patients expressed no preference.

The patient sagittal diameter at the iliac crest level was on average 20.6% greater on standing (median 30.0 interquartile range [26.0 to 34.0] cm) when compared to the supine position (24.0 [22.3 to 28.0] cm; $p < 0.001$). Soft tissue displacement was seen to vary between the male and female subgroups and at different anatomical levels (Table 2). The changes were evident radiographically when the images were compared side-by-side (Figures 2–4).

The pelvis was consistently more anteriorly tilted in the female subgroup, evidenced by the larger PSSC values (Figures 1–3 and Table 3). The PSSC varied in both supine (range −25 to 67 mm) and erect (-36 to 47 mm) position with the majority rotating posteriorly on weight-bearing. Only five patients (8.3%) had anterior tilt of their pelvis when moving between the two positions, evidenced by an increased PSSC distance on standing.

Image quality evaluation

In terms of image quality, a high level of agreement was noted with an interobserver ICC (95% CI) of 0.97 (0.95 to 0.98) for supine and 0.96 (0.94 to 0.97) for the erect radiographs. Out of the total possible score of 100, the image quality was reduced on the erect images [median 78 interquartile range (69 to 85)] by 9% in comparison with supine [87 (81 to 91), $p < 0.001$]. The quality metrics showed a statistically significant difference for overweight and obese cohorts ($p < 0.05$), but not for the normal BMI ($p = 0.80$) subgroup. Overall, a weak negative correlation was noted between image quality and BMI r= - 0.30 ($p = 0.018$). Image quality scores, for individual anatomical areas, are summarised in Table 4.

Radiation dose

Data were compared between the two erect SID groups (140 and 180 cm) across a range of values (Tables 5 and 6). The radiation dose values demonstrated no statistically significant differences ($p > 0.05$), therefore, for all further analyses, these have been considered as a single group. Although no statistically significant differences were evident between the dose values for patients with, and without, prostheses, these did have some dependency on patient position and therefore, given the small numbers, the impact of a hip replacement on dose cannot be fully understood (Table 6).

The mAs values were higher in the erect position [range 3.5 to 200, median 30.9, interquartile range (18.0 to 54.4)] than supine exposures [5.1 to 75.2, 14.6 (10.6 to 21.6)]. Overall, the DAP was 46% higher in the erect position (median 1121, interquartile range [859 to 2303] mGy.cm^2), and this was statistically significant when compared with the supine position [757 (548 to 1142) mGy.cm^2; $p < 0.001$]. The effective dose ([.17 (0.13 to 0.33) mSv] was 47% higher in the erect position when compared to supine [0.12 (0.08 to 0.18) mSv; $p < 0.001$]. A statistically significant correlation was evident between the effective dose and sagittal abdominal diameter in the both the supine and erect positions (0.78 *vs* 0.74, $p < 0.01$). When the differences in effective dose between the two projections were calculated, there was a moderate correlation with increasing BMI, this was statistically significant (0.71, $p = 0.01$).

Table 2. Patient sagittal diameter in both supine and standing posture

	Mean sagittal diameter, cm ± SD					
	Supine			Standing		
	LCM	IC	GT	LCM	IC	GT
Male	28.9 ± 5.2	26.8 ± 4.7	24.3 ± 3.0	33.5 ± 4.7	31.5 ± 5.2	26.5 ± 3.5
Female	24.7 ± 4.6	24.3 ± 4.3	22.0 ± 3.4	29.8 ± 5.1	29.1 ± 5.3	25.5 ± 5.6
Total	26.2 ± 5.2	25.2 ± 4.6	22.8 ± 3.5	31.1 ± 5.2	30.0 ± 5.3	25.9 ± 4.9

GT, Greater tuberosity; IC, Iliac crest; LCM, Lower costal margin;SD, standard deviation.

Figure 2. Paired radiographs of a 50-year-old female (a - erect, b - supine) with normal BMI. Note the organ displacement evidenced by the position of an intrauterine contraceptive device (small arrows). BMI, body mass index.

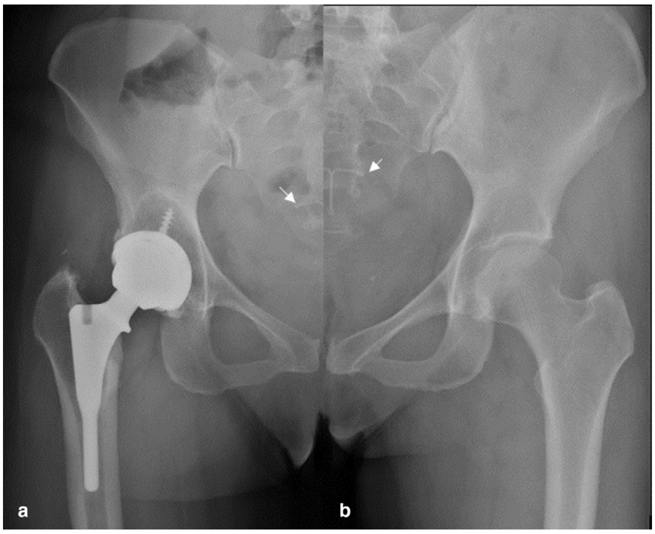
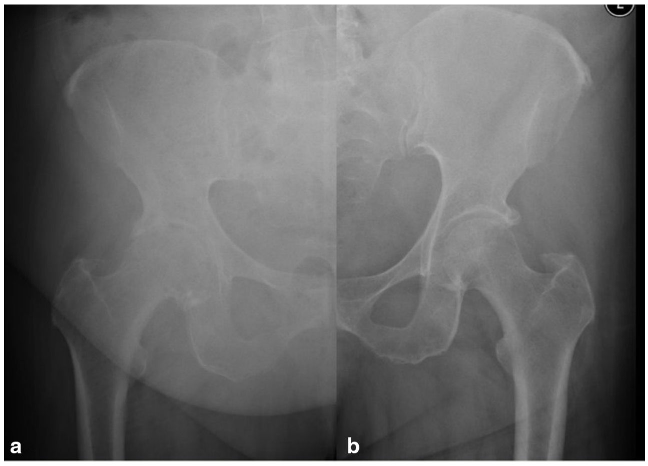


Figure 4. Paired X-ray images of an obese 60-year-old female (erect right, supine left) demonstrating a change in pelvic tilt and marked soft tissue displacement.



DISCUSSION

To the authors' knowledge, this is the first study to formally evaluate the differences between supine and erect pelvis radiographs in terms of IQ and radiation dose. The increase in sagittal diameter seen on standing negatively influenced the image quality, particularly in the overweight and obese groups. This correlates with others who have observed that technically better images are obtained supine, particularly for obese patients where the hip can be obscured by the abdominal pannus when the patient is standing.[1,9] Data from our study does provide some additional evidence of the effect of the mobility of the abdominal pannus. Visualisation of the sacrum and sacroiliac joints was poorer in the erect position, this could be the result of the inferior gravitational pull of the abdominal pannus as evidenced in the images. Such differences were not as evident for the more distal structures, such as the proximal femora and trochanters, and may further support this theory. In many image quality studies, an overall single value of image quality is provided and used as the comparator when defining optimised settings. Our work is novel in that we have considered and compared individual anatomical points and whether they can be individually optimised as part of

Figure 3. Paired X-ray images of an overweight 89-year-old male (erect right, supine left) demonstrating a change in pelvic tilt and soft tissue displacement.

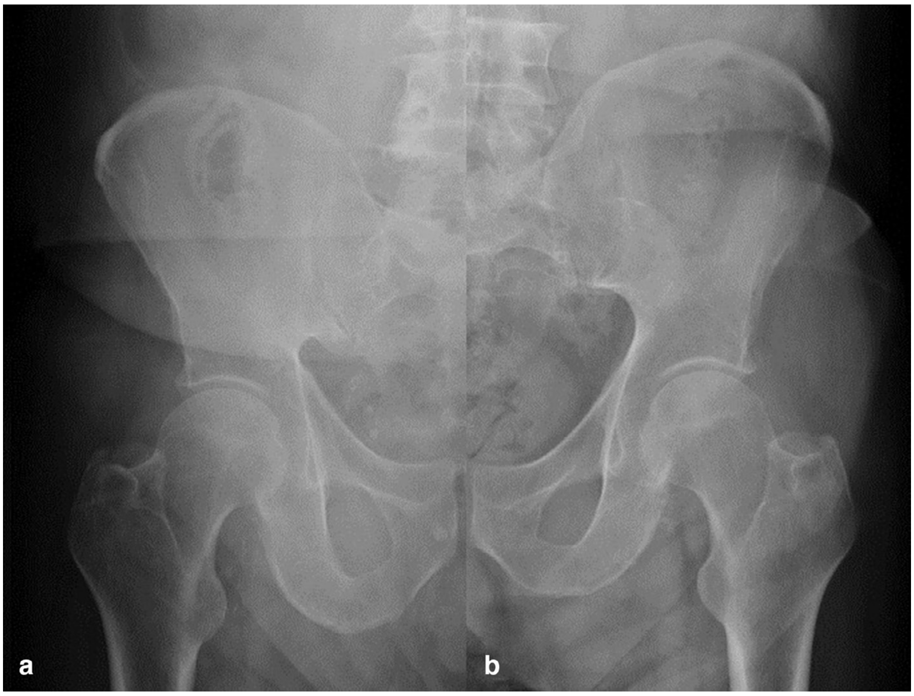


Table 3. PSSC distance in supine and standing

		PSSC distance (mean mm, SD)			
	n	Supine	Erect	Difference	Significance (*p*)
Male	22	12.0 ± 18.2	−4.9 ± 20.9	14.0 ± 12.2	<0.001
Female	38	33.2 ± 17.3	19.2 ± 15.6	16.8 ± 16.3	<0.001
Total	60	25.4 ± 20.3	15.0 ± 13.8	10.4 ± 21.1	<0.001

PSSC, pubic symphysis to sacrococcygeal.

practice. Future work could demonstrate, *e.g.* when evaluating hip pain, an erect technique could deliver equitable image quality for relevant key structures.

Consistent with other studies,[6–9,11,13,25] the pelvis was confirmed to tilt posteriorly on standing, although this was not universal and anatomical changes varied between patients. The PSSC, often referred to as the sacrococcygeal symphysis (SCS) or sacrococcygeal distance (SCD), is a proxy for PT assessment in the absence of a lateral projection,[7,9,25–27] other measures of tilt were considered but the PSSC has been validated across multiple studies, is insensitive to any patient rotation and does not require complex calculations. Differences in tilt between patients provide evidence of anatomical variation and individual spinopelvic alignment.[28] These results contradict the work of Siebenrock et al[7] who defined a standard measure of PSSC for males (32.3 mm) and females (47.3 mm) and suggested any variation from this would be the result of inappropriate image acquisition technique. There have been calls to standardise imaging approaches,[3,4] radiographs demonstrating a PSSC distance outside of the published parameters[7] are considered to be as result of poor radiographic quality,[4] rather than anatomical variation at a patient level.

Standardised positioning is essential to support accurate measurements of cup wear in patients with arthroplasties.[38] But worryingly, Mascarenhas et al[2] propose that a craniocaudal angle should be applied until the optimal PT, a PSSC of 1 to 3 cm, is achieved, a technique which would obviously alter the version of the acetabulum. Both patient rotation and changes in the sagittal PT, and beam angulation can also alter the apparent version of the acetabular cup. In this study, we used a femoral-based centring point, rather than the traditional pelvis-based one(s) surmising the changes in tilt on weight-bearing, differences in ASIS and pubic symphysis position could alter the beam centre if a standard technique had been utilised. However, further research is required to validate this approach or establish the most effective centre location to minimise distortion of anatomy and variability between different patient positions.

A key outcome was the significant increase in radiation dose in the erect position. This is particularly relevant given the relevance of the erect pelvis in investigation of dysplasia and FAI in adolescents and young adults. The effect of patient position on radiation dose has been evaluated previously for other body parts,[15,19,20] but these studies only considered soft tissue compression when moving from a supine to a prone position. Importantly, this study demonstrated a significant increase in abdominal diameter when standing, regardless of BMI. Patient thickness is an acknowledged factor in radiographic technique and resultant image quality.[38–40] The AP thickness at the iliac crest was key in this study which utilised AEC chambers located over both ilia. Importantly, the supine sagittal abdominal diameter at the iliac crest is a predictor of visceral fat, which has been acknowledged as the strongest predictor of radiation dose, even during CT scanning.[41] This perhaps suggests that the abdominal diameter, as a measure of adiposity, is an appropriate measure for studies involving the abdominopelvic region. Although changes in the position of abdominopelvic organs was not specifically evaluated in this study, it has previously been confirmed.[23,24,43] If denser abdominopelvic organs reposition to within the imaging field on

Table 4. Comparison of the visualised anatomy individual image quality scores by technique

Visualised anatomy	Median (IQR)		Significance (*p*)
	Supine	Erect	
Iliac crests	91.9 (76.5–94.7)	81.9 (68.2–082.6)	0.465
Sacroiliac joints	87.1 (59.8–91.3)	65.6 (49.3–70.0)	0.273
Hip joints	93.6 (73.9–95.2)	77.4 (62.9–80.0)	0.273
Femoral necks	95.8 (80.0–96.1)	87.5 (70.3–82.1)	0.273
Proximal femora	97.6 (80.6–98.4)	93.9 (77.6–94.5)	0.465
Trochanters	97.7 (79.6–98.3)	92.3 (47.2–71.0)	0.465
Sacrum	83.2 (61.0–85.3)	59.0 (49.2–72.9)	0.144
Pubic & ischial rami	96.3 (80.7–96.6)	81.3 (74.0–87.0)	0.144

IQR, interquartile range.
Scores are percentages of the maximum permissible mark for each criterion.

Table 5. Comparison of the values across the 140 cm (n = 37) and 180 cm (n = 23) SID groups

Variable	SID (cm)	Mean ± SD	Median (range)
Patient thickness (cm)	140	28.7 ± 5.5	28.5 (18.0–43.5)
	180	26.6 ± 3.5	26 (19.5–33.0)
Dose area product (mGy cm^2)	140	1881 ± 1833	1100 (376–10775)
	180	1391 ± 704	1125 (475–3157)
Effective dose (mSv)	140	0.29 ± 0.29	0.17 (0.13–0.44)
	180	0.21 ± 0.11	0.17 (0.13–0.28)
% of maximum possible IQ score	140	76 ± 15	80 (35–96)
	180	76 ± 9	78 (49–91)

IQ, Image quality; SD, Standard deviation; SID, Source image distance.

standing, this may increase the tube output when an automatic exposure control is employed. The diagnostic reference level (DRL) for pelvis radiography is based on the supine position, if such a technique becomes mainstream an additional erect DRL may be required to support image and dose optimisation.

The exposure parameters (kVp and AEC) used for the study was based on a previous experimental study which considered dose and image quality.[43] As the patients were having both supine and erect examinations, a higher kVp was chosen in an attempt to maintain quality and manage dose. The source–subject distance utilised was greater than in other research on this topic[3,43] but adoption of an even greater distance for the erect position part way through the study was not effective in limiting dose.

One interesting finding was the patient preference for standing radiography which contradicts Gold et al[1] who feel that the supine position should be more comfortable. The large proportion of older patients in our study may have influenced this outcome but patient experience and the potential for movement during an erect examination warrant further investigation.

This project does, however, suffer from limitations. The relatively small sample size limits subgroup analysis of different age groups or subsequent clinical outcomes. Nor does the cohort demographics enable the results to be generalised to a wider population, specifically younger patients. It must be noted that all patients were considered eligible for inclusion and the presence of hip prostheses may have impacted on the ability to evaluate quality on some images. As authors we could have opted to exclude these patients, however, this would not reflect clinical practice and eliminated an important patient cohort. Moreover, the needs of a wider multidisciplinary team (orthopaedic surgeon, radiographer, radiologist, physicist and other referrers) and the patient should be considered within further technique optimisation, particularly with respect to image quality criteria and diagnostic acceptability. We would also like to provide some additional discussion regarding the use of the CALDose_X software. This software uses conversion coefficients that were calculated using male and female (MAX06 & FAX06) phantoms using 36 projections for 10 commonly performed X-ray examinations.[35] The CALDose_X package allows the user to define the tube potential, X-ray beam filtration, position of the patient (standard or supine) and sex. Such an approach builds on the limitations of other software and phantoms, which do not allow simulation of moving from a supine to an erect position, *e.g.* PCXMC 2.0.

CONCLUSION

In line with other studies, our findings confirmed variation in sagittal tilt of the pelvis and rotation of the pelvis posteriorly in most participants. Radiographic image quality was reduced for the standing technique, particularly in larger patients, as a result of the increased abdominal soft tissue diameter.

The standing pelvis projection also resulted in an average radiation dose increase of 47%, again linked to patient adiposity. This technique may support clinical decision-making, in terms

Table 6. Comparison of study metrics between radiographic positions for patients with, and without, hip prostheses

	Supine			Erect		
	Prosthesis	No prosthesis	Significance (p)	Prosthesis	No prosthesis	Significance (p)
n (%)	19 (31.6)	41 (68.4)		19 (31.6)	41 (68.4)	
PSCC (mm)[a]	11.0 (3.0 to 23.0)	32.0 (14.5 to 44.0)	0.004	2.0 (-18.0 to 13.0)	19.0 (4.0 to 27.5)	0.013
Image quality[a]	0.81 (0.78 to 0.86)	0.90 (0.84 to 0.93)	<0.001	0.74 (0.68 to 0.80)	0.80 (0.80 to 0.80)	0.005
Effective dose (mSv)[a]	0.12 (0.16 to 0.37)	0.11 (0.12 to 0.31)	0.818	0.22 (0.16 to 0.42)	0.15 (0.12 to 0.34)	0.116

PSSC, Pubic symphysis to sacrococcygeal.
[a]Values denoted by are expressed as median (IQR).

of diagnosis and treatment planning in specific patient groups but requires further consideration if it is to be included within standard practice, particularly for larger patients. Image optimisation should include definition of an effective centring point, consider the utilisation of increased distance and develop patient-specific exposure parameters to reflect their body habitus.

FUNDING

College of Radiographers Industry Partnership Scheme grant.

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