Optimum positioning for AP pelvis radiography: a literature review

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Abstract

Aim: Pelvic radiography is used for the identification of hip joint changes, including pathologies such as osteoarthritis (OA). Several studies have recommended the position for this radiological procedure should be standing and not supine in order to reflect the functional appearances of the hip joint. The aim of this literature review was to evaluate pelvis radiography positioning with respect to the image appearances and information provided for clinical decision making. Aside from this, the review will also consider potential recommendations for the radiographic technique for an erect pelvis projection.

Method: A literature search was performed using databases / abstract systems (ScienceDirect, Web of Science, PubMed and Medline). Only articles written in English were included.

Results: Twenty-five articles were identified. Findings from the review describe the effect of repositioning from supine to erect on a series of specific hip measurements. These include pelvic tilt, joint space width and the acetabular component.

Conclusion: Evidence within the literature illustrates that in several studies there were differences when repositioning from supine to standing for a number of pelvic metrics. Standing positioning is promoted by some authors as this may facilitate the early diagnosis of hip joint pathology and assist in the planning of surgical interventions. Literature is very limited on how to optimally perform erect pelvis radiography and this should be an area for future research.

Key words: pelvis radiography, standing position, supine position, hip pathology, technique, pelvis tilt.

Introduction

Over the past two-decades orthopaedic evaluation and treatment of hip pain has improved dramatically[1, 2]. This is mainly due to the improved understanding of structural hip pathologies, including acetabular dysplasia of the hip (AD) and femoroacetabular impingement (FAI)[3, 4]. AD is an abnormality of the hip joint consisting of an abnormal relationship between the femoral head and acetabulum. The dysplastic acetabulum is shallow and steeply oriented[5]. FAI is the collision between parts of the femoral head and acetabular rim. There are three types of FAI[6]. The first is cam-FAI in which the deformity occurs at the femoral head junction. The second type is pincer-FAI where the femoral neck abuts against the acetabular rim and occurs due to the femoral head sitting deep within the acetabulum[7]. The third type is combined impingement where both cam and pincer types are present. Both AD and FAI are considered early signs of osteoarthritis (OA). OA is expected to become the fourth most common disability in the United Kingdom (UK) by 2020[8] and it is also a leading cause of hip pain[9]. Early diagnosis of people suffering from hip pathology is, therefore, vitally important to ensure appropriate management strategies are established.

Advances in medical imaging equipment such as computed tomography (CT) and magnetic resonance imaging (MRI) provide three-dimensional images which offer accurate diagnosis for hip joint pathologies[10]. Despite these developments, projection radiography remains crucial in the diagnosis and follow-up of most hip joint disorders such as FAI and AD. Primary reasons behind this are that it is a simple, accessible and cheap technique with a relatively low radiation dose and importantly it provides valuable clinical information[11]. Despite these advantages, precise evaluation of the hip joint still poses challenges to the clinician, especially in cases of a mild structural abnormality[4, 12].

Alongside visual analysis of the imaging appearances a number of key radiographic measurements are used in the evaluation of hip anatomy and the diagnosis of hip joint disorders[13, 14]. Examples include centre-edge angle (CEA), acetabular index (AI) and joint space width (JSW) which are used to demonstrate AD[5, 15]. CEA is the most useful indicator of hip dysplasia, and it is the degree of lateral femoral head coverage in the frontal plane[16]. AI refers to the orientation of the acetabular roof[17] and is increased in developmental dysplasia. Head/neck offset and alpha angle are alternative metrics in the diagnosis of FAI[18–20]. In addition, acetabular morphology is important to identify changes in bony architecture which may underpin the FAI. JSW is measured at the narrowest point on projection radiography[21] and reduces with joint cartilage loss and OA progression.

Pelvic tilt (PT) is considered one of the most important factors that effects radiographic outcome measures. The pelvis can tilt in a lateral or antero-posterior (AP) orientation, with the former most commonly related to leg length discrepancy and the latter rotation (flexion or extension) of the pelvis and is influenced by posture. PT is measured by defining the angle between the line connecting the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS) and a horizontal line[22].

Anterior PT rotates the pelvis forward and causes the acetabulum to be orientated posteriorly facing, defined as retroversion. In healthy people, if the pelvic X-ray image is acquired with increased PT then this will lead to false acetabular retroversion appearances, which can affect the diagnosis of FAI. Ultimately, inaccurate measurements, which may result from radiographic positioning, could lead to inadequate diagnosis and poor quality treatment[11].

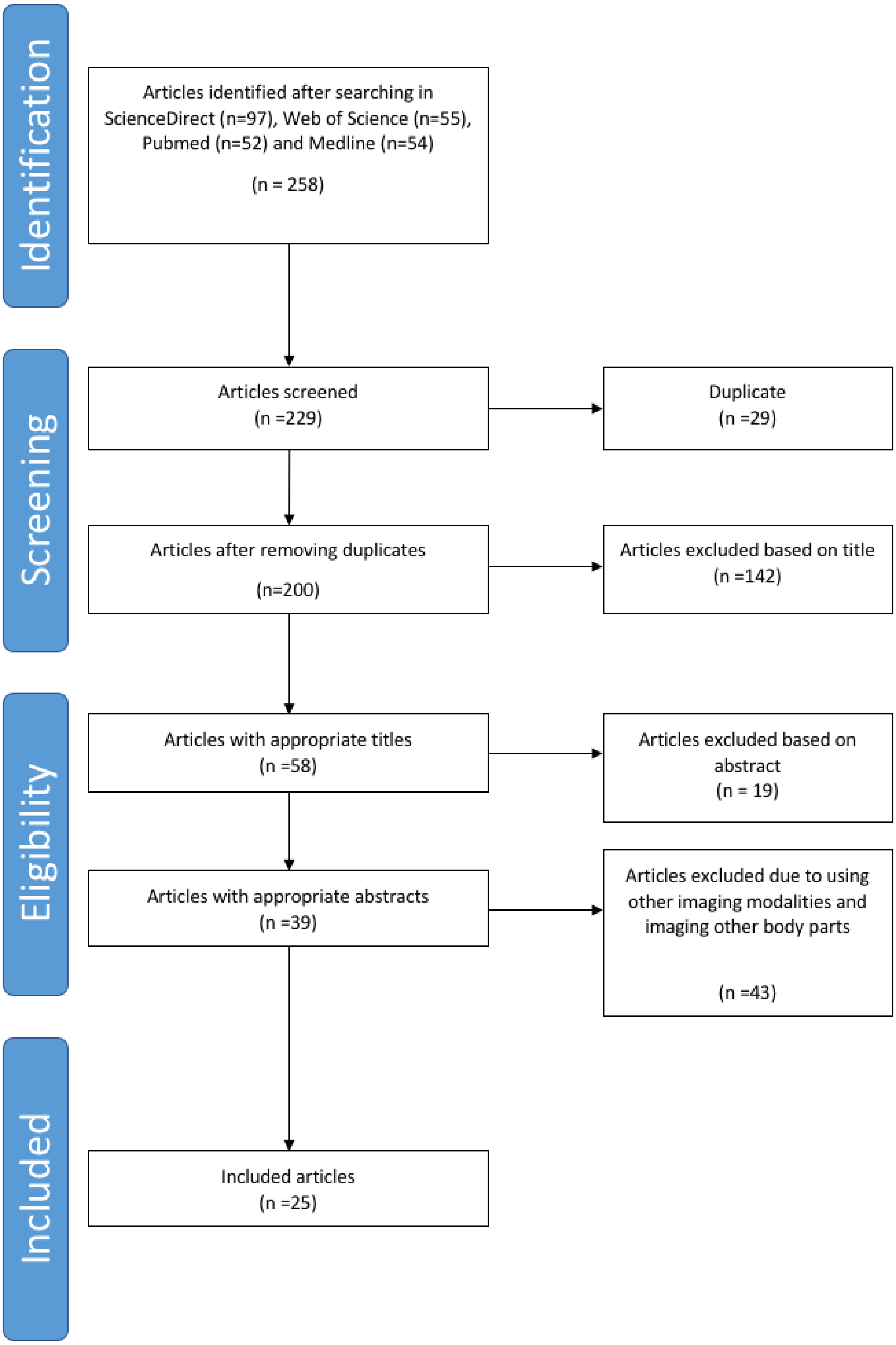
Traditionally, an AP pelvis X-ray image is undertaken with the patient in the supine position. As hip pain often presents during weight bearing and daily functional activities, such as walking and running, some advocate that pelvic imaging should be performed in the erect position in order to provide more clinically useful information[23–25]. Supporting this, several studies have reported that there are changes in the orientation (tilt) of pelvis as the posture changes i.e moving from supine to standing[26–29].

The aim of this literature review was to evaluate erect over supine pelvic imaging, with respect to imaging appearances and the diagnostic information provided. Aside this, the review will also consider, whether recommendations can be provided on the optimum radiographic technique for erect AP pelvis radiography.

Methods

Peer reviewed literature was selected from four medical journal databases: ScienceDirect, Web of Science, PubMed and Medline. Search terms used Medical Subject Headings (MESH) and key words included hip, pelvis radiography, standing and supine pelvis, erect pelvis, weightbearing, total hip replacement, osteoarthritis, dysplasia, femoroacetabular impingement, developmental dysplasia of hip. Only articles written in English were included. There were no time limitations placed on the search; this was to ensure that significant seminal studies were included. The search used Boolean operators (AND, OR & NOT) to further narrow the results. To ensure that the information used within the review was accurate only submissions from peer-reviewed journals were selected. Furthermore, only those articles with unrestricted accessibility to their full-text were considered eligible for inclusion. Publications which only used standing and supine positions were also included. Articles that did not involve projection radiography, such as MRI and ultrasound were excluded. However, articles focusing on the differences between the two positions, but using other imaging modalities were included if deemed relevant. Moreover, the articles that used the two positions (erect and supine) for other body parts were also removed. Further details of the literature search and identification processes are detailed in **Figure 1**.

Figure 1. Flowchart illustrating the article identification and selection process for the review.



Results

Twenty-five articles were identified using the previously defined search criteria, with a large proportion emanating from mainland Europe. Key aspects of the articles are summarised in **Table 1** (see appendix). Findings can be divided into three main groups: the impact on the PT and other pelvic measurements, the acetabular component of a joint replacement prosthesis and JSW. The discussion focused on these subgroups to help understand the information provided and in order to simplify the discussion. Six sections were chosen since they are the most common measurements used to evaluate anatomical changes between the two positions (erect and supine).

Discussion

This section discusses the most important findings regarding the impact of repositioning from supine to the standing and the value of the standing pelvis X-ray image. The discussion also considers the impact of repositioning on the different radiographic appearances. Moreover, this section highlights the different positions and imaging techniques that were used to obtain pelvis X-ray images in the reviewed literature. However, if the position or technique is not described then the authors did not provide technical details on how images were obtained.

The impact of repositioning on PT

Several studies[26, 28] have concentrated on examining the difference between supine and erect positioning on PT. The results appear to be contradictory as some authors found differences between erect and supine, whilst others did not.

Troelsen et al. (2008)[26], recommended the erect pelvis position for people suffering from developmental dysplasia of the hip (DDH). Their study was conducted on 31 DDH patients and two images were acquired, one supine and one erect. Supine images were acquired with the lower extremities parallel to each other and the feet internally rotated 15º to 20º. Erect images were acquired with the legs parallel to each other and with enough internal rotation for both feet to touch. Pelvic rotation, JSW, acetabular version, CEA and AI were measured. Study findings indicated that there was a change in the PT between positions for both genders. In a standing position PT was greater in females (13°-14°) when compared to males (6°-7°), however, this was not statistically significant (p=0.14 to 0.70). Additionally, there was a statistically significant change in CEA from 1.3° to 1.6° (P<0.006), AI increased from 1.6 to 2.3 (P<0.003) but JSW was not affected (P=0.16). Extension to the pelvis was noted in the standing position, identified by the reduction in the distance between the sacro-coccygeal joint and symphysis pubis (SC-S) (p<0.005). Images demonstrating the crossover sign (an acetabular radiographic finding associated with retroversion and pincer- FAI) reduced from 11 in supine to 4 in the erect position.

A further study by Ala Eddine et al.[27] was undertaken in 2001 using 24 patients to investigate if the pelvis was individualised for everyone and whether morphological changes exist between the supine and erect positions. Lateral pelvis X-ray images were acquired in standing and supine positions for a healthy group of volunteers. The results demonstrated a number of important pelvic differences on repositioning; for example, 22 patients demonstrated acetabular retroversion and two patients showed anteversion when moving from supine to erect. Differences were significant for changes in pelvis flexion and version (p=0.0001). The authors concluded that one of the reasons for the displacement of prostheses is due to pelvic measurement methods. These often depend on a CT scan alone for evaluating the hip joints. Since the CT scan is performed supine it is unlikely to take into account these changes when people are standing and potentially increases the error in arthroplasty location during surgery[27].

Findings from Ala Eddine et al.,[27] concurred with a recent study by Pierrepont et al., (2017)[28] who evaluated the effect of three positions on PT in 1517 patients. X-ray images were acquired in the supine, erect and in sitting positions. PT was obtained using a supine CT scan and also measured from lateral X-ray images in standing and sitting positions. The mean supine, erect and sitting PT were 4.2°, -1.3° and 0.6°, respectively. Moving from supine to erect, the pelvis was observed to rotate posteriorly by ≥13°, increasing the risk of acetabular anteversion. These results highlight the increased risk of anterior loading and instability for people undergoing total hip replacement. Accordingly, the authors discussed the importance of surgical planning and the determination of the acetabular cup orientation when relying on supine imaging. They concluded that supine imaging may lead to suboptimal orientation of the acetabulum in functional positions (erect, sitting). In addition, assessment by function, using erect / load bearing pelvis imaging, was recommended as essential step for patients undergoing total hip replacement.

Babisch et al. (2008)[29] reported the effect of repositioning on PT and acetabular cup inclination. Forty patients were imaged supine and erect and the results showed a significant difference in PT between positions (p<0.001). Within this work, the mean PT was -10.4° and -5° for erect and supine positions, respectively, a change of 5.4°. Konishi et al., 199330 reported significant differences between standing and supine positions in PT. In their study they evaluated 54 healthy volunteers using AP and lateral pelvis X-ray images. Study findings demonstrated an increase in PT by 5º (p=0.0001) between positions.

Previous studies[26, 27, 29] have demonstrated statistically significant differences between the two positions, however, comparisons must be taken cautiously since the research used different radiographic projections (AP and lateral). Furthermore, they also used different groups of participants (healthy volunteers, DDH patients, patients with hip replacements). Also, there were differences in the imaging modality used, including radiography and reconstructed CT images generated to mimic AP X-ray images. A clear description of the standing position was not included in several studies and as such, the effects of differences in position could not be evaluated. However, there is evidence that PT and hence the CEA and acetabulum are affected when moving from supine to standing in both healthy and symptomatic patient groups. It should be recommended that standing radiography should be considered when people are suffering from hip pain and when early diagnosis is paramount.

PSI to evaluate to PT

Some authors have used measures of pelvic sagittal inclination (PSI) to evaluate the impact of pelvic orientation (tilt) changes. Tamura et al., (2014)[31] assessed one hundred and sixty three patients in a study to determine the different spinal factors affecting PSI, in both erect and supine positions. AP pelvis images were acquired in the standing position with the beam centred over the superior margin of symphysis pubis. Whole spine lateral radiographs were obtained in the standing position. Patients were asked to stand 'relaxed', with their hands positioned on a support bar in order to remove the hands from the primary radiation field. Supine measurements were obtained using pre-operative CT scans. In 25% of the patients the PSI changed by >10° after moving from supine to standing and for the other 75% the change was -6.9° (P<0.001)[31].

A further study was conducted by Tamura et al. in 2017[32] to investigate the longitudinal differences between the two positions on PSI. Patients were imaged in supine and standing at 1, 5 and 10 years after total hip arthroplasty (THA). Pre-operative supine images were obtained from CT scans and for standing the patient was asked to stand in a comfortable position and the X-ray beam was centred over superior margin of the symphysis pubis. Ten years post THA there was more than a 10º increased in PSI posteriorly when moving from standing to supine, however, this was not felt to cause late dislocation, therefore the authors concluded that supine positioning is still valid for acetabular component diagnosis.

A study undertaken by Miki (2012)[33] evaluated whether the supine position is still suitable for people who have a large pelvic inclination when standing. Ninety-one patients were imaged in the two positions. Pelvis inclination ranged from -21º to 5º in the supine and standing positions, respectively and there was a strong correlation between the two positions (R=0.88). Another study[34] was conducted to evaluate the differences between the two positions using lateral X-ray images. Twenty-three patients were imaged and the results showed no significant differences in lumbar lordosis (p=0.06), sacral inclination (p=1.00) and slip angle (p=0.55) between positions.

Evaluating PT using an inclinometer

Evaluating PT using other techniques is well established, an inclinometer is a widely accepted test but would not be subject to the same geometrical differences from moving between erect and supine positions during projectional radiography. As such, an absence of any differences using an inclinometer can not necessarily be translated across to radiographic assessments. Anda et al., (1990)[35] measured PT in 40 healthy young adults using an inclinometer for erect and supine positions. No significant differences existed between the erect and supine positions based on this nonradiological test. Similar results were found by Nishihara et al., in (2003)[36] when studying 101 arthroplasty patients. Mayr et al., (2005)[37] measured PT in 120 adult volunteers in the supine and erect positions using a digitising arm. A digitizing arm generates a computer model from a physical object by sampling 3D coordinates one at a time. Within this work, mean PT were 6.7° and 5.6° in the erect and supine, respectively, and elderly people more than 60 years old were shown to have more pelvic inclination in the standing position (8.7°). The mean pelvic inclination differences between the two positions was statistically significant -1.1° (p=0.007).

PT and acetabular cup orientation

A group of investigators studied the effect of PT on acetabular cup orientation[38]. Lembeck et al., (2005)[38] measured PT on 30 volunteers using a combination of an inclinometer and ultrasonography. The average PT was -4° and -8° in supine and erect positions, respectively. Moreover, for every 1° of pelvis reclination there was 0.7° of cup anteversion. The authors concluded that clinicians must take particular care about increasing the risk of arthroplasty dislocation due to an incorrectly located acetabular component, when pelvis measurements are taken in the supine position[38]. Lembeck reported that in the supine position -4 degree of PT gives 2.8° of cup anteversion, which was unlikely to affect surgical outcomes. However, they stated that when standing -8°of PT generated 5.6° more anteversion, which is a particularly critical value. Findings from Lembeck et al.,[38] were also in line with Ala Eddine et al.[27] who found an increasing error of cup anteversion when depending on supine CT images alone.

The impact of repositioning on the acetabulum

A number of studies[39–41] were conducted to evaluate acetabulum morphology as it plays an important role in clinical decision making with regards to choosing the most appropriate treatment option. Differences between the standing and supine positions were assessed on pincer-FIA[39] patients. Forty-six patients complaining of hip pain were evaluated. Measures indicative of PT and AD were evaluated, including the distance between the symphysis and coccyx tip (T-S), the SC-S, retroversion signs, CEA and inclination were measured. The standing and supine images were taken with the lower extremities 15º internally rotated. Moving from supine to standing the T-S distance decreased from 19 mm to 6 mm (p≤0.001), and the SC-S distance decreased from 47 mm to 32 mm (p≤0.001). These distances are related to PT, which means PT is less in the standing position than for supine. Findings regarding the crossover sign, the number of the hips that demonstrated it decreased from 18 (supine) to 9 (standing) (23% to 13%; p≤0.001), CEA did not change (p=0.64), but inclination angle significantly increased between positions (p=0.002). The authors concluded that AP pelvis imaging in the standing position must be standardised when evaluating hip abnormalities, and that caution must be exercised by clinicians if they use images acquired in the supine position when evaluating FAI [39].

Evaluating the effect of supine and standing pelvis positions on acetabular version was studied by Ross et al., in (2015)[40]. The results were obtained from 50 FAI patients by taking a standing pelvis X-ray image and reconstructing supine images using pre-operative CT data. Patients were positioned for the supine examination with their legs abducted and patellae orientated anteriorly. This position was considered to provide a neutral supine PT. Study findings showed the acetabular orientation differed between the two positions and the authors proposed that position must be taken into account when diagnosing and treating FAI patients. Acetabular version increased by 2º ($p<0.001$) when moving from a supine to a standing position as a result of increased posterior PT. During standing, there was an increase in hip flexion by 3º and an increase in internal rotation and abduction by 3º ($p<0.001$). Regarding the signs of acetabular retroversion, study findings showed no significant changes between the two positions ($p=0.21$, $p=0.31$, $p=0.60$ for the crossover, posterior wall and ischial spine signs, respectively), however, in 27% of participants the change in acetabular orientation resulted in a loss of the crossover sign in the standing position[40]. This in turn may lead to an inaccurate diagnosis and increase the risk of ineffective treatment.

Differences between the two positions were significant in the study by Polkowski et al., (2012)[41] which was undertaken to determine whether the acetabular measurements change. Standing images were obtained using the EOS system, a slit beam digital radiography system designed to enable three-dimensional low dose imaging, and supine images obtained from CT scans. Results showed that acetabular inclination and version changed in standing position ($p<0.0001$ for cup anteversion and $p=0.017$ for inclination). Appropriate attention needs to be given when comparing the EOS system with images rendered from CT data. Differences between positions could be attributed to differences in image acquisition techniques between the two systems. With an absence of validation data caution must exist when interpreting differences between modalities.

Similar findings were obtained by Lazennec et al (2011)[42] when comparing the acetabular orientation between the two positions. AP pelvis X-ray images were obtained in standing and sitting positions while supine positions were acquired from CT scans. Acetabular anteversion changed from 24.2º in supine to 31.7º, 38.8º in standing and sitting positions, respectively ($p<0.001$). There was correlation between standing and supine but not with sitting. The authors concluded that supine positions, using CT data acquired before THA, introduces bias and consideration should be taken when evaluating the functional positions[42].

Nishihara et al. (2003)[36] used AP pelvis X-ray images acquired in supine, erect and sitting positions for 101 patients who had undergone THA. The purpose of the study was to determine the acetabular component position and the safe zone (optimum orientation of acetabulum component during total hip replacement) in different pelvis locations. For imaging, the source-to-image distance (SID) was 150 cm centred over the superior margin of the symphysis pubis. Supine images were obtained using CT scans. 90% of the patients had 10º or less difference in pelvic flexion angle (tilt) between erect and supine, and 20º between erect and sitting ($R=0.84$; $p<0.0001$). Based on their results the authors concluded that the supine position is as practical as the functional standing position and considered it a suitable reference frame when evaluating acetabular component orientation. Also, the pelvis flexion angle can be predicted for erect and sitting positions from the supine position. However, for the remaining 10% of cases they needed more extensive evaluation when the acetabular component position needed to determined[36].

A further study was conducted by Khan et al. (2016)[43] investigating the effect of repositioning on the acetabular cup orientation. Fourteen patients with bilateral joint replacements were included in this study with AP pelvis images acquired in both positions. The cup anteversion was measured using software which enables orientation of the cup to be accurately assessed with less than 1º error and was based on two dimensional images. There were statistically significant differences in the mean cup anteversion angle 1.84º (p=0.02), greater in the standing position than supine. Cup orientation is highly affected by PT and orientation. As anteversion increases the cup pressure, contact and lubricating loss will also increase. This will lead to greater wear of the THA and potential for hip dislocation[43].

Au et al. (2014)[44] found a significant increase in the acetabular inclination and anteversion in the standing position when they conducted a study to see if the safe zone of the cup remained safe when moving from supine to standing. During this study 30 patients were imaged with AP and lateral images in both positions. The results showed that PT, inclination and anteversion increased significantly when people stand (p<0.0001) and importantly they are likely not to be in the same safe zone as when supine (p<0.0001).

A recent study by Jackson et al., in 2015[45] also determined the changes on the acetabulum component between the standing and supine. One hundred and thirteen THA patients were imaged on the same day in the two positions. Supine images were obtained using conventional radiography and standing images using EOS. The results showed that the mean changes in acetabulum component inclination and version were 4.6° in supine and 5.9° in standing (p<0.0001). Changes were more than 5° in 43% and 53% of hip inclination and version, respectively. The authors recommended that a standing position should be considered when planning for THA and when determining the optimal acetabular orientation.

Impact of repositioning on joint space width (JSW) and central edge angle (CEA)

A comparison of erect and supine pelvis radiography was conducted in 2008 by Fuchs-Winkelmann et al.[46] to determine whether there was a difference in the demonstration of OA signs. Measurements of acetabular roof obliquity (AI), JSW and CEA were acquired using erect and supine X-ray images in patients with DDH. The results illustrated variations between supine and erect, AI values were greater, CEA smaller and minimum JSW was reduced in the standing position (p<0.001 all metrics)[46]. Okano et al., (2008)[47] found significant differences in JSW in 162 OA hip patients when imaging people in supine and erect positions. In standing positions, patients were asked to stand in a comfortable position and distribute their weight equally on both feet, rotating their feet inwards by 15º±5º. The X-ray beam was centred on the pubis symphysis using a SID of 110 cm and with images obtained using fluoroscopy. Supine images obtained using the same parameters resulted in the JSW being greater for supine positions ($p<0.0001$). Moreover, patients with JSW more than 1 mm in the supine position decreased by more than 1 mm in standing and the authors recommended standing position for the evaluation of hip pain[47].

In contrast to the work by Fuchs-Winkelmann et al.,[33] Auleley et al., (1998)[48] found no significant differences in the JSW between images acquired in the erect and supine position. The study by Auleley et al., included patients with and without the presence of OA. X-ray images were again obtained using fluoroscopy and a 110cm SID, with 15º of internal rotation of both feet. The central ray was positioned at the level of the symphysis pubis. JSW was measured using a 0.1 mm graduated magnifying glass and was greater in the standing position than when supine. However, these differences were less than 0.64 mm, with 95% limits of agreement (LOA) between the two positions being −0.46 mm to 0.62 mm, and this represents normal for OA appearances on projection radiography.

Findings obtained from another study by Terjesen & Gunderson (2012)[49] do not vary significantly from the previously reported study[31]. The aim of this study was to evaluate the reliability of AP pelvis X-ray images for DDH patients and compare the hip parameters between erect and supine. Patients were positioned with their legs parallel and the imaging technique used a 120 cm SID and a central ray positioned 3 cm above the symphysis pubis. Mean differences between the supine and standing positions for CEA ranged from -1.1º to 0.0º (LOA, −8 to 7°) and JSW less than 0.1 mm (LOA, −0.6 to 1.1 mm). Neither of these differences were considered clinically significant. Accordingly, the authors continued to use supine imaging for evaluating hip problems.

A further study by Evison et al, (1987)[50], which examined measurement differences between erect and supine images for 21 patients, also found no statistically significant differences. In this case, the authors provided technical details for imaging including a 100 cm SID, 70-75 kVp and 50-100 mAs. In 95% of their cases there was less than 1 mm differences in JSW between the positions. However, the authors recommended the erect position for some patient groups such as pre- and post-operative patients but not for routine clinical practice.

There are limitations to the assessment of JSW as the location of the measures was not consistently reported, with some confirming the smallest measure, whilst others suggested the middle of the superior joint space was evaluated. In addition, different positions, SID, centring points and acquisition parameters were identified, where described. Moreover, no consistent position for standing and supine acquisitions were used, some studies obtained the images with internal rotation of the feet while other studies maintained a parallel position. It has been proven from previous research that there is an effect of changing these parameters on image quality and radiation dose[51, 52].

These could also have an effect on clinical decisions, for instance, when the image quality is higher the diagnosis may be more likely to be correct.

Limitations

Whilst a growing number of studies have investigated changes in pelvic measurements resulting from moving between standing and supine positions there have been no investigations of any changes in radiation dose resulting from the different positions. Further studies are warranted which should investigate optimum radiographic acquisition factors for standing pelvic radiography. Within the reviewed literature there was commonly an absence of details regarding the precise positioning of patients for both supine and erect pelvic radiography. Some authors did attempt to standardise technique but the effectiveness of this was not discussed. Further research is required in order to understand how variations in radiographic technique can affect pelvic measurements and potentially procedural outcomes.

In should be noted that a number of studies[27-30, 34, 44] have reported on the use of lateral pelvis images and their utility in the management of hip pathologies. The purpose of our review was to compare likely variations between erect and supine AP pelvic imaging and not to evaluate the utility of a lateral projection. It is accepted that there would be a role for lateral pelvic radiography in certain clinical manifestations, however there would be dose implications when incorporating this projection.

Conclusion

In conclusion, from the literature it is clear that there are changes to the pelvis that occur when repositioning people from supine to standing. There is inconsistency in the literature exacerbated by the different methods and techniques that have been used when evaluating the changes in position. In addition, research has generally been concentrated in specific patient groups (i.e. OA or FAI), limiting generalisability of the research. Moreover, no studies have considered the radiation dose and overall image quality while repositioning from supine to a standing position. Trends within the publications analysed suggest that there are statistically significant differences in PT, pelvic version, CEA, PSI and JSW between positions. With many symptoms of hip pathologies only being present when weight-bearing there are growing arguments supporting imaging in this position. It is likely that both supine and erect pelvic radiography, using a standardised technique, provides the opportunity for accurate measurements. However, erect radiography provides a greater opportunity to evaluate the effects of force on the hip joint and also the postural orientation of the pelvis. Such information can allow the identification of more subtle cases of pathology or provide more robust information for treatment planning. Ultimately, understanding that there can be differences in measurements between techniques is important and both supine and erect pelvic radiography will have a role in the investigation and management of hip disease.

Descriptions of radiographic technique for erect radiography is limited within the literature and none of the publications discussed within this work have provided any evidence of validation on whether their approach to imaging is optimum. Additionally, some studies utilise non-standardised imaging for measurements such as reconstructed data from CT scans or standing lateral spine X-ray images. Equally, no research has been conducted into optimising erect pelvis radiography, from an image quality or dosimetry perspective. This represents a major gap in the literature and must be the focus of future work. Movement of abdominal and pelvic tissue is likely to be different between positions and is likely to have an effect on radiation dose and image quality. This would need to be considered when defining technical parameters as it is important to optimise the examination and provide maximum diagnostic information.

References

[1] M.B. Gerhardt, A.A. Romero, H.J. Silvers, D.J. Harris, D. Watanabe, and B.R. Mandelbaum, The prevalence of radiographic hip abnormalities in elite soccer players, Am. J. Sports Med. **40**(3), 584–588 (2012).

[2] K. Herr and M. Titler, Acute Pain Assessment and Pharmacological Management Practices for the Older Adult With a Hip Fracture: Review of ED Trends, J. Emerg. Nurs. **35**(4), 312–320 (2009).

[3] R. Iorio, W.J. Robb, W.L. Healy, *et al.*, Orthopaedic surgeon workforce and volume assessment for total hip and knee replacement in the United States: Preparing for an epidemic, J. Bone Jt. Surg. - Ser. A **90**(7), 1598–1605 (2008).

[4] J.G. Skendzel, A.E. Weber, J.R. Ross, *et al.*, The Approach to the Evaluation and Surgical Treatment of Mechanical Hip Pain in the Young Patient, J. Bone Jt. Surg. **95**(18), e133 (2013).

[5] C.B. Lee and Y. Kim, Special Patients and Conditions: Acetabular Dysplasia, in *Hip Jt. Restor.*(Springer, New York, 2017), pp. 703–712.

[6] S. Mannava, A.G. Geeslin, S.J. Frangiamore, *et al.*, Comprehensive Clinical Evaluation of Femoroacetabular Impingement: Part 2, Plain Radiography, Arthrosc. Tech. **6**(5), e2003–e2009 (2017).

[7] H. Eijer and T. Hogervorst, Femoroacetabular impingement causes osteoarthritis of the hip by migration and micro-instability of the femoral head, Med. Hypotheses **104**, 93–96 (2017).

[8] NICE, *osteoarthritis: care and mangment in adults CG177*, NICE (2014).

[9] C. Kim, K.D. Linsenmeyer, S.C. Vlad, *et al.*, Prevalence of radiographic and symptomatic hip osteoarthritis in an urban United States community: The Framingham osteoarthritis study, Arthritis Rheumatol. **66**(11), 3013–3017 (2014).

[10] S. Glyn-Jones, A.J.R. Palmer, R. Agricola, *et al.*, Osteoarthritis, Lancet **386**(9991), 376–387 (2015).

[11] M. Tannast, S.B. Murphy, F. Langlotz, S.E. Anderson, and K.A. Siebenrock, Estimation of pelvic tilt on anteroposterior X-rays - A comparison of six parameters, Skeletal Radiol. **35**(3), 149–155 (2006).

[12] M. Wilson, J. J., & Furukawa, Evaluation of the Patient with Hip Pain - p27.pdf, Am. Fam. Physician **89**(1), 27–38 (2014).

[13] S. Jacobsen, Adult hip dysplasia and osteoarthritis Studies in radiology and clinical

epidemiology, Acta Orthop. (Suppl **77**(324), (2006).

14 T. Kappe, T. Kocak, C. Neuerburg, S. Lippacher, R. Bieger, and H. Reichel, Reliability of radiographic signs for acetabular retroversion, Int. Orthop. **35**(6), 817–821 (2011).

15 L. Fa, Q. Wang, and X. Ma, Superiority of the modified tonnis angle over the tonnis angle in the radiographic diagnosis of acetabular dysplasia, Exp. Ther. Med. **8**(6), 1934–1938 (2014).

16 H. Ömeroglu, A. Biçimoglu, H. Aguş, and Y. Tümer, Measurement of center-edge angle in developmental dysplasia of the hip: A comparison of two methods in patients under 20 years of age, Skeletal Radiol. **31**(1), 25–29 (2002).

17 M.J. Van Der Bom, M.E. Groote, K.L. Vincken, F.J. Beek, and L.W. Bartels, Pelvic rotation and tilt can cause misinterpretation of the acetabular index measured on radiographs, Clin. Orthop. Relat. Res. **469**(6), 1743–1749 (2011).

18 J.C. Clohisy, R.M. Nunley, R.J. Otto, and P.L. Schoenecker, The frog-leg lateral radiograph accurately visualized hip cam impingement abnormalities, Clin. Orthop. Relat. Res. (462), 115–121 (2007).

19 R. Agricola and H. Weinans, Femoroacetabular impingement: What is its link with osteoarthritis?, Br. J. Sports Med. **50**(16), 957–958 (2016).

20 A.S. Ranawat, B. Schulz, S.F. Baumbach, M. Meftah, R. Ganz, and M. Leunig, Radiographic Predictors of Hip Pain in Femoroacetabular Impingement, HSS J. **7**(2), 115–119 (2011).

21 G.R. Auleley, a Duche, J.L. Drape, M. Dougados, and P. Ravaud, Measurement of joint space width in hip osteoarthritis: influence of joint positioning and radiographic procedure., Rheumatology (Oxford). **40**(ii), 414–419 (2001).

22 S. Sprigle, N. Flinn, M. Wootten, and S. McCorry, Development and testing of a pelvic goniometer designed to measure pelvic tilt and hip flexion, Clin. Biomech. **18**(5), 462–465 (2003).

23 A. Henebry and T. Gaskill, The effect of pelvic tilt on radiographic markers of acetabular coverage, Am. J. Sports Med. **41**(11), 2599–2603 (2013).

24 C. Melnic, A Systematic Approach to Evaluating Knee Radiographs with a Focus on Osteoarthritis, J. Orthop. Rheumatol. **1**(2), 1–6 (2014).

25 A. Troelsen, L. Rømer, S. Kring, B. Elmengaard, and K. Søballe, Assessment of hip dysplasia and osteoarthritis: Variability of different methods, Acta radiol. **51**(2), 187–193 (2010).

26 A. Troelsen, S. Jacobsen, L. Rømer, and K. Søballe, Weightbearing anteroposterior pelvic radiographs are recommended in DDH assessment, Clin. Orthop. Relat. Res. **466**(4), 813–

819 (2008).

[27] T. Ala Eddine, H. Migaud, C. Chantelot, A. Cotten, C. Fontaine, and A. Duquennoy, Variations of pelvic anteversion in the lying and standing positions: Analysis of 24 control subjects and implications for CT measurement of position of a prosthetic cup, Surg. Radiol. Anat. **23**(2), 105–110 (2001).

[28] J. Pierrepont, G. Hawdon, B.P. Miles, *et al.*, Variation in functional pelvic tilt in patients undergoing total hip arthroplasty, Bone Joint J. **99–B**(2), 184–191 (2017).

[29] J.W. Babisch, F. Layher, and L.P. Amiot, The rationale for tilt-adjusted acetabular cup navigation, J. Bone Jt. Surg. - Ser. A **90**(2), 357–365 (2008).

[30] N. Konishi and T. Mieno, Determination of acetabular coverage of the femoral head with use of a single anteroposterior radiograph. A new computerized technique, J. Bone Jt. Surg. - Ser. A **75**(9), 1318–1333 (1993).

[31] S. Tamura, M. Takao, T. Sakai, T. Nishii, and N. Sugano, Spinal factors influencing change in pelvic sagittal inclination from supine position to standing position in patients before total hip arthroplasty, J. Arthroplasty **29**(12), 2294–2297 (2014).

[32] S. Tamura, S. Nishihara, M. Takao, T. Sakai, H. Miki, and N. Sugano, Does Pelvic Sagittal Inclination in the Supine and Standing Positions Change Over 10 Years of Follow-Up After Total Hip Arthroplasty?, J. Arthroplasty **32**(3), 877–882 (2017).

[33] H. Miki, T. Kyo, and N. Sugano, Anatomical Hip Range of Motion After Implantation During Total Hip Arthroplasty With a Large Change in Pelvic Inclination, J. Arthroplasty **27**(9), 1641–1650. (2012).

[34] G.R. Dhakal, A. Biswas, S. Rathinavelu, D.K.K. Patel, and S. Basu, Comparison between Standing and Supine Lateral Radiographs in Low Grade Spondylolisthesis, J. Manmohan Meml. Inst. Heal. Sci. **2**(4), 14–18 (2015).

[35] S. Anda, S. Svenningsen, T. Grontvedt, and P. Benum, Pelvic inclination and spatial orientation of the acetabulum, Acta radiol. **31**(4), 389–394 (1990).

[36] S. Nishihara, N. Sugano, T. Nishii, K. Ohzono, and H. Yoshikawa, Measurements of Pelvic Flexion Angle Using Three-Dimensional Computed Tomography, Clin. Orthop. Relat. Res. **411**(411), 140–151 (2003).

[37] E. Mayr, O. Kessler, A. Prassl, F. Rachbauer, M. Krismer, and M. Nogler, The frontal pelvic plane provides a valid reference system for implantation of the acetabular cup: spatial orientation of the pelvis in different positions., Acta Orthop. **76**(6), 848–53 (2005).

[38] B. Lembeck, O. Mueller, P. Reize, and N. Wuelker, Pelvic tilt makes acetabular cup

navigation inaccurate, Acta Orthop. **76**(4), 517–523 (2005).

39 T.J. Jackson, A.A. Estess, and G.J. Adamson, Supine and Standing AP Pelvis Radiographs in the Evaluation of Pincer Femoroacetabular Impingement, Clin. Orthop. Relat. Res. **474**(7), 1692–1696 (2016).

40 J.R. Ross, E.P. Tannenbaum, J.J. Nepple, B.T. Kelly, C.M. Larson, and A. Bedi, Functional Acetabular Orientation Varies Between Supine and Standing Radiographs: Implications for Treatment of Femoroacetabular Impingement, Clin. Orthop. Relat. Res. **473**(4), 1267–1273 (2015).

41 G.G. Polkowski, R.M. Nunley, E.L. Ruh, B.M. Williams, and R.L. Barrack, Does standing affect acetabular component inclination and version after THA?, Clin. Orthop. Relat. Res. **470**(11), 2988–2994 (2012).

42 J.Y. Lazennec, P. Boyer, M. Gorin, Y. Catonné, and M.A. Rousseau, Acetabular anteversion with CT in supine, simulated standing, and sitting positions in a THA patient population, Clin. Orthop. Relat. Res. **469**(4), 1103–1109 (2011).

43 M. Khan, T. Beckingsale, M. Marsh, and J. Holland, Difference in the acetabular cup orientation in standing and supine radiographs, J. Orthop. **13**(3), 168–170 (2016).

44 J. Au, D.M. Perriman, T.M. Neeman, and P.N. Smith, Standing or supine x-rays after total hip replacement-when is the safe zone not safe?, HIP Int. **24**(6), 616–623 (2014).

45 J. V. Tiberi, V. Antoci, H. Malchau, H.E. Rubash, A.A. Freiberg, and Y.M. Kwon, What is the Fate of Total Hip Arthroplasty (THA) Acetabular Component Orientation When Evaluated in the Standing Position?, J. Arthroplasty **30**(9), 1555–1560 (2015).

46 S. Fuchs-Winkelmann, C.D. Peterlein, C.O. Tibesku, and S.L. Weinstein, Comparison of pelvic radiographs in weightbearing and supine positions, Clin. Orthop. Relat. Res. **466**(4), 809–812 (2008).

47 K. Okano, N. Kawahara, K. Chiba, and H. Shindo, Radiographic joint space width in patients with Crowe Type-I dysplastic hips, Clin. Orthop. Relat. Res. **466**(9), 2209–2216 (2008).

48 G.R. Auleley, B. Rousselin, X. Ayral, R. Edouard-Noel, M. Dougados, and P. Ravaud, Osteoarthritis of the hip: agreement between joint space width measurements on standing and supine conventional radiographs., Ann. Rheum. Dis. **57**, 519–523 (1998).

49 T. Terjesen and R.B. Gunderson, Reliability of radiographic parameters in adults with hip dysplasia, Skeletal Radiol. **41**(7), 811–816 (2012).

50 G. EVISON, P.A. REILLY, J. GRAY, and A. CALIN, Comparison of Erect and Supine Radiographs of the Hip, Rheumatology **26**(5), 393 (1987).

51 R. Heath, A. England, A. Ward, *et al.*, Digital Pelvic Radiography: Increasing Distance to Reduce Dose., Radiol. Technol. **83**(1), 20–28 (2011).

52 A.S. Manning-Stanley, A.J. Ward, and A. England, Options for radiation dose optimisation in pelvic digital radiography: A phantom study, Radiography **18**(4), 256–263 (2012).

Table 1. Summary of publications included within the review article.

Authors/Year	Aim / Purpose	Design / Methods	Key findings	Conclusions
Evison et al.,1987[50]	Determine if the joint space width (JSW) differs between supine and erect positions.	**n**=21 **Subjects:** With prostheses and normal **Method:** supine and standing pelvis radiography.	Less than 1 mm difference in JSW between the two positions.	No significant differences.
Anda et al., 1990[35]	Measured pelvis inclination in supine and standing positions.	**n**= 40 **Subjects:** healthy adults. **Method:** pelvic inclinometer.	Increased pelvis inclination by 0.4° in males and 2.3° in females, between positions.	No significant differences.
Konishi et al., 1993[30]	Establish a method for estimating acetabular coverage.	**n**=54 **Subjects:** healthy volunteers. **Methods:** antero-posterior (AP) and lateral X-ray images.	Increased pelvic tilt (PT) by 5° between positions.	Significant differences identified (PT).
Auleley et al., 1998[48]	Evaluate the effect of erect position on JSW measurements for pelvis radiography.	**n**= 46 **Subjects:** patients with and without osteoarthritis (OA). **Methods:** supine and standing pelvis radiography using fluoroscopy.	Differences in JSW were less than or equal to 0.64 mm.	No significant differences.

Ala Eddine et al., 2001[27]	Determine whether the pelvic equilibrium is constant over time and between standing and supine positions.	<u>**n**</u>= 24 <u>**Subjects:**</u> healthy adults. <u>**Methods:**</u> standing and supine lateral X-ray images.	Increased angulation in standing position ranging from 6° to 8°.	Significant differences identified (pelvic version).
Nishihara et al., 2003[36]	Evaluate the safe zone of the acetabular component between supine, standing and sitting.	<u>**n**</u>= 101 <u>**Subjects:**</u> total hip arthroplasty (THA) patients. <u>**Methods:**</u> standing, sitting pelvis X-ray images and supine images obtained from CT scans.	10º or less difference in pelvic flexion angle between the two positions.	No significant differences.
Lembeck et al., 2005[38]	Evaluate the impact of PT on cup orientation.	<u>**n**</u>= 30 <u>**Subjects:**</u> healthy people. <u>**Methods:**</u> inclinometer.	Increase PT by 4° in standing positions.	Significant differences identified (PT).
Mayr et al., 2005[37]	Evaluate the changes in pelvic inclination between standing and supine.	<u>**n**</u>= 120 <u>**Subjects:**</u> healthy adults. <u>**Methods:**</u> 3-dimensional digitising arm (equipment used for generating a computer model from a physical object by sampling 3D co-ordinates).	Increase PT by 1° in standing positions.	No significant differences.
Troelsen et al., 2008[26]	Whether the weightbearing position alters radiographic interpretation	<u>**n**</u>= 41 <u>**Subjects:**</u> dysplasia patients. <u>**Methods:**</u> standing and supine X-ray images.	Increase in PT for males (6° to 7°) and females (13° to 14°).	Significant differences identified (PT).
Babisch et al., 2008[29]	Study the effect of position on PT and cup values.	<u>**n=**</u> 40 <u>**Subjects:**</u> dysplasia and OA patients. <u>**Methods:**</u> CT and lateral X-ray images.	Decrease in PT by 5.4°in the standing position.	Significant differences identified in PT.

Fuchs et al., 2008[46]	Whether OA signs and angles differ between supine and standing.	**n=** 61 **Subjects:** developmental dysplasia of the hip (DDH) patients. **Methods:** supine and standing pelvis X-ray images.	Central edge angle (CEA) less for standing by 3.6° and JSW by 0.49 mm .	Significant differences identified in CEA & JSW.
Okano et al., 2008[47]	Compare the differences in JSW between supine and standing.	**n=**162 **Subjects:** OA patients. **Methods:** standing and supine X-ray images using fluoroscopy.	JSW shorter by 0.52 mm in the standing position.	Significant differences identified (JSW).
Terjesen et al., 2011[49]	Examine the reliability of radiographic measurements for DDH patients and if these differ between supine and standing.	**n=**51 **Subjects:** DDH patients. **Methods:** supine and standing pelvis X-ray images.	Difference in CEA from supine to standing was -1.1 to 0.0. Less than 0.1 mm difference in JSW between the two positions.	No significant differences.
Lazennec et al., 2011[42]	Compare the acetabular component between standing, supine and sitting positions.	**n=**328 **Subjects**: THA patients. **Methods**: standing and sitting pelvis radiography while supine images obtained using computed tomography (CT) scans.	Increased cup anteversion by 7.5º in standing position.	Significant differences identified (cup anteversion).
Miki et al., 2012[33]	Evaluate functional pelvis position in standing and supine.	**n=**91 **Subjects**: THA patients. **Methods**: navigation system.	Pelvis inclination ranged from -21º to 5º.	No significant differences.

Polkowski et al., 2012[41]	Differences in acetabular cup measurements between standing and supine position.	**n=**46 **Subjects**: THA patients **Methods**: EOS for standing position. Supine position obtained from CT scan.	Increase of more than 5º in cup anteversion in the standing position.	Significant differences identified (cup anteversion).
Tamura et al., 2013[31]	Evaluate the changes in pelvic sagittal inclination (PSI) between standing and supine.	**n=**163 **Subjects:** THA patients. **Methods:** pelvis and spine lateral radiography standing. Supine radiography obtained from CT scans.	Changes in PSI was -6.9° from supine to standing.	Significant differences identified (PSI).
Au et al., 2014[44]	Identified if the safe zone varied between standing and supine.	**n=**30 **Subjects:** THA patients **Methods:** AP and lateral X-ray images in supine and standing positions.	Reduction in PT by 9.0° and increase in anteversion by 10.2° in standing. Increase pelvis inclination by 2.2° in the standing position	Significant differences identified (PT, anteversion & inclination).
Ross et al., 2015[40]	Studied the impact of the position on acetabular version and range of motion (ROM).	**n=**50 **Subjects**: Femoroacetabular impingement (FAI) patients. **Methods**: standing pelvis X-ray images, supine X-ray images obtained from CT scans.	Increase by 2º on acetabular version and 3º on hip flexion in the standing position.	Significant differences identified (acetabular version & ROM)
Dhakal et al., 2015[34]	Demonstrate the differences between standing and supine of lumbosacral region.	**n=**23 **Subjects**: spondylolisthesis patients **Methods**: standing and supine lateral	Increase lumber lordosis by 8° in standing position.	Borderline significant differences identified (lordosis)

		X-ray images.		
Tiberi et al., 2015[45]	Evaluate the change in acetabular component between the standing and supine.	**n=**113 **Subjects**: THA patients **Methods**: supine pelvis radiography. EOS in the standing position.	Increase in acetabulum inclination and version was 4.6° and 5.9°, respectively in the standing position.	Significant differences identified (acetabular inclination and version)
Khan et al., 2016[43]	Assess the changes of acetabular orientation between standing and supine.	**n=**14 **Subjects**: THA patients. **Methods**: supine and standing pelvis radiography.	Increase in cup anteversion by 1.84º in the standing position.	Significant differences identified (cup anteversion).
Jackson et al., 2016[39]	Evaluate the differences between standing and supine for pincer-FAI patients.	**n=**46 **Subjects**: FAI patients **Methods**: standing and supine pelvis radiography.	Cross over sign decreased by 11% and inclination angle increased by 1.1°	Significant differences identified (crossover sign, inclination angle)
Pierrepont et al., 2017 [28]	Presented changes to PT for different functional positions.	**n=**1517 **Subjects**: THA patients. **Methods**: standing and sitting lateral X-ray images. Supine X-ray images obtained from CT scans.	Pelvis rotation by 6° from supine to standing.	Significant differences identified (PT).
Tamura et al., 2017[32]	Evaluated the differences in PSI between standing and supine.	**n=**70 **Subjects**: THA patients **Methods**: standing pelvis radiography. Supine images obtained from CT scans.	More than 10º differences in PSI from standing to supine position.	Significant differences identified (PSI).