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# The radiation dose, clinical and anatomical implications of erect lumbar spine radiography: A single centre pre-post implementation evaluation.

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## **Abstract**

### **Introduction**

Lumbar radiographs remain a common imaging examination despite strategies to reduce their use. Many authors have demonstrated benefits in changing from traditional supine and recumbent lateral projections to a prone and/or erect orientation. Despite evidence of clinical and radiation dose optimisation, widespread adoption of these strategies has stalled. This article describes the single-centre implementation and evaluation of erect PA and lateral projections.

### **Method**

This was an observational study pre- and post-implementation of an erect imaging protocol. Patient BMI, image field size, source image and source object distances and DAP were collected together with assessment of radiographic spinal alignment and disc space demonstration. Effective dose was calculated with organ specific doses.

### **Results**

76 (53.5%) patients were imaged in the supine AP and recumbent lateral position, 66 (46.5%) had erect PA and lateral radiographs. Despite the larger BMI of the erect cohort and similar field sizes, effective dose was lower in the PA position by an average of 20% ( $p < 0.05$ ), however, no significant difference in lateral dose. Anatomical improvements were evident with greater visualisation of intervertebral disc spaces in the PA erect ( $t = -9.03$ ;  $p < .001$ ) and lateral ( $t = -10.298$ ;  $p < .001$ ) orientations. Erect PA radiographs demonstrated a leg length discrepancy in 47.0% (0.3-4.7cm) and a scoliosis in 21.2% of cases, with a significant link between these findings ( $r(64) = .44$ ;  $p < .001$ ).

### **Conclusion**

Erect lumbar spine radiography provides information on clinical outcomes not available with recumbent projections. The improvements in anatomical visualisation and radiation dose reduction supports the local change in practice.

## **Implications for practice**

- Erect imaging can reduce effective dose with an optimised acquisition protocol
- Additional pathological information can be revealed by the erect posture.
- Postural awareness is critical to interpret images accurately.

## **Introduction**

The spine is a complex anatomical structure designed to maintain an upright stance in humans and as such is subject to stress from multidirectional motion and axial loading. This transfer of forces within the trunk has been identified as a causal factor in the development of low back pain and osteoarthritis.<sup>1-3</sup> Spinopelvic malalignment compensatory mechanisms, such as flexion of the knees or hips, pelvic tilt, lumbar or cervical hyperlordosis, thoracic hyperkyphosis and lateral curvature, are employed by the body to maintain balance and function in the presence of pathology.<sup>4,5</sup> These mechanisms are usually observed with increasing age, however, some may be observed as a result of developmental (or acquired) anomalies such as leg length discrepancy (LLD). It is also important to acknowledge that the shape of the lumbar spine is influenced by posture and as such variations in alignment are observed across supine, seated and standing positions.<sup>6</sup>

Although the number of lumbar radiographs has declined as a result of increasing referrals to cross-sectional imaging and recognition of its limitations, it remains a common imaging examination<sup>7</sup> and is still recommended for investigation of lower back pain if the result is likely to change management.<sup>8</sup> Standing radiographs are often used in assessment of spinopelvic alignment, particularly in surgical planning both for spinal and/or hip surgery.<sup>9-12</sup> In addition, they are also recommended in spinal trauma to assess stability.<sup>13</sup> All radiation doses should be kept to as low as reasonably practicable (ALARP) and this should be reflected in departmental image acquisition protocols. This is especially relevant as lumbar spine is one of the highest ionising radiation yielding radiographic examinations due to the dense structures and radiosensitive organs found within the trunk of the human body and this is exacerbated with obesity.<sup>14</sup>

Within UK the most common lumbar radiographic projections are the supine anteroposterior (AP) and recumbent lateral.<sup>15,16</sup> Contrary to this, many authors have confirmed the benefits of prone<sup>16-20</sup> or erect imaging<sup>21-24</sup> to reduce radiation dose and/or improve anatomical visualisation, particularly in a functional stance. The latest UK national diagnostic reference levels (DRL) for different radiographic examinations were published in 2019,<sup>25</sup> based on 2010 data.<sup>26</sup> In line with the 'accepted' technique, AP and recumbent lateral lumbar spine dose data is cited, however the implications of different projections are not acknowledged. This article describes the implementation, and subsequent evaluation, of erect postero-anterior (PA) and lateral projections for non-trauma lumbar spine radiography in a single centre.

## **Method**

A change in imaging protocol had been approved by the local radiology governance and management groups following review of the literature as part of the annual review of protocols. The evaluation was planned to ensure there were no negative clinical or radiation dose consequences as a result of the change and also consider the implications for the local DRL. This was an observational study with each examination technique utilising the local standard of care at the time of the patient attendance. Institutional ethical approval for data collection was obtained (EC26227) as the project was undertaken as part of a postgraduate academic award. Data was collected for individuals

referred for lumbar spine radiography by their general practitioner or hospital outpatients prior to and following the change in acquisition technique.

#### Image acquisition

All imaging was performed using an Evolution DRX-1 digital radiography system (Carestream Health Inc, Rochester, NY) with a focal spot size of 1.2mm and grid ratio of 12:1 centred at 140cm. AP supine and recumbent left lateral radiographs (unless a dextroconvex lumbar curvature was observed on the initial projection) were obtained in 2018 using a routine source to image receptor distance (SID) of 115cm. The standard exposure parameters used were 85kV for the supine AP and 90kV for the recumbent lateral with variation from this at the radiographer discretion. Leg position (extended or flexed) had been recorded on an audit form with no attempt to influence an individual's radiographic practice. In 2020 the erect imaging protocol was implemented and patients were positioned in the PA position and left lateral position (following review of the PA projection) against the wall stand. The hands of the patients were placed on their clavicles, ensuring adequate elevation of the elbows. Following a series of experiments similar to Alukić et al,<sup>18</sup> an erect SID of 140cm was determined optimal with 90kV for the PA and 95kV for the lateral exposures. All exposures used central chamber on the automatic exposure control (AEC).

#### Data collection

Information collected included age and gender together with height and weight to enable calculation of the body mass index (BMI) as is standard in DRL establishment. Source image distance (SID), standard table thickness and source object distance (SOD) were used to calculate individual patient AP diameter at the level of the central ray. In addition, the exposure factors and dose area product (DAP) were also recorded. Resultant images were reviewed for the number of intervertebral disc spaces fully visualised, and the exposed area which was calculated from the collimated width and length measurements obtained using the tools on a PACS workstation (Enterprise Imaging, Agfa Gaevert, Belgium). Spinal alignment in the supine and lateral recumbent orientation is influenced by radiographer positioning but direct measurement of lumbar lordosis was obtained on the recumbent and erect lateral radiographs, measuring from the superior borders of L1 to S1. The Cobb angle was also calculated on the erect PA radiographs. In there erect PA position an assessment was made of the height of the visualised iliac crests and/or femoral heads (if included in the exposed area) and observed differences, which would indicate a LLD, were measured using the orthopaedic PACS tools.

#### Data analysis

Data was collated in Microsoft Excel with statistical analysis carried out using SPSS v28 (IBM Inc, Armonk, NY). Effective and absorbed organ specific dose was calculated using the Monte Carlo simulation software PCXMC 2.0 (STUK, Radiation and Nuclear Safety Authority, Helsinki, Finland). Data was assessed for normality using the Shapiro-Wilk test. For data with a normal distribution mean and standard deviation have been reported together with two-sided t-test to compare across groups. Conversely median and interquartile range (IQR) with Mann-Whitney U test has been reported for data which is not normally distributed. Pearson correlation and Chi-squared was undertaken to assess for the relationship between continuous and categorical variables respectively.

### **Results**

Data was collected on 142 patients, 76 (53.5%) had examinations performed in the supine AP and recumbent lateral position, with a further 66 (46.5%) following the implementation of the erect imaging protocol. No significant difference was seen in the gender composition, with both groups having a higher proportion of women (supine n=54/76, 71.1% vs erect n=45/66, 68.2%;  $\chi^2=0.138$ ,  $p=.710$ ). Overall the erect cohort was slightly younger with a higher BMI and a resultant larger AP diameter (Table 1).

Table 1: Comparison of the demographic data across the groups

	Orientation	Mean $\pm$ SD / Median (IQR)	Significance (p)
Age (years)	Supine	67.0 (53.0-77.0)	.061
	Erect	60.5 (47.8-74.5)	
BMI	Supine	27.6 (24.7-32.6)	.005
	Erect	30.9 (26.5-37.4)	
AP diameter (cm)	Supine	23.9 $\pm$ 4.4	<.001
	Erect	28.6 $\pm$ 4.99	

On the PA erect radiographs, a measurable LLD was identified on 47.0% (n=31/66). The amount varied (range 0.3-4.7cm; mean 1.1cm) with 10 patients having a difference of more than 1cm and three patients more than 2cm. An erect spinal curvature was present in 59.1% (n=39/66; range 1.6 to 23.5°; mean 5.2°; SD 5.9°) with 14 (21.2%) patients demonstrating a scoliosis (>10° curve). As shown in figure 1 the LLD had a direct association with a spinal curvature ( $r(64)=-.44$ ;  $p<.001$ ).

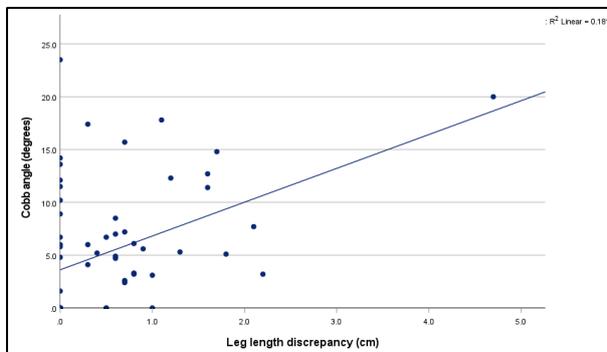


Figure 1: The relationship between leg length discrepancy and spinal curvature for erect radiographs

Leg position varied for the supine AP projection with only 57.9% recorded as obtained with both legs flexed. The number of intervertebral disc spaces fully visualised was higher on the erect projections in both the PA ( $t=-9.03$ ;  $p<.001$ ) and lateral ( $t=-10.298$ ;  $p<.001$ ) orientations (Figures 2,3 and 4).

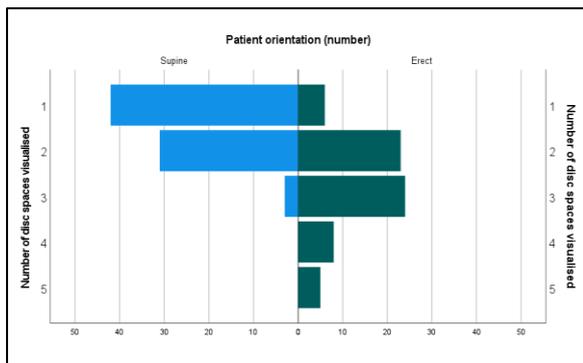


Figure 2: Number of intervertebral disc spaces visualised on the supine AP and erect PA radiographs

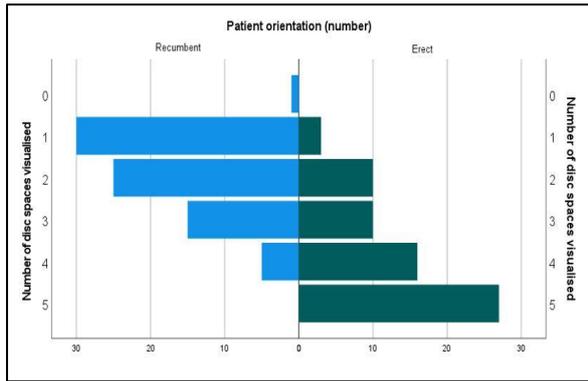


Figure 3: Number of intervertebral disc spaces visualised on the recumbent and erect lateral radiographs



Figure 4: Example PA erect and lateral radiographs on a female patient with a BMI of 28.

The exposed field size was not significantly different regardless of the patient orientation (Table 2). The DAP was higher in the erect position for both projections, however the effective dose was significantly lower for the erect PA compared to the supine AP examination (Table 2).

Table 2: Comparison of outcomes across orientations

	Orientation	Mean $\pm$ SD / Median (IQR)	Significance (p)
AP/PA field size (cm <sup>2</sup> )	Supine	769.0 $\pm$ 142.7	.372
	Erect	748.0 $\pm$ 136.0	
Lateral field size (cm <sup>2</sup> )	Recumbent	721.0 $\pm$ 155.8	.086
	Erect	763.8 $\pm$ 136.2	
AP/PA DAP (mGy/cm <sup>2</sup> )	Supine	749.5 (455.2-1346.8)	.064
	Erect	1001.5 (589.5-1566.0)	
Lateral DAP (mGy/cm <sup>2</sup> )	Recumbent	1336.5 (869.0-1957.0)	<.001
	Erect	2058.0 (1417.0-3313.0)	
Effective dose AP/PA (mSv)	Supine	0.20 (0.13-0.29)	.009
	Erect	0.16 (0.10-0.22)	
Effective dose Lat (mSv)	Recumbent	0.19 (0.13-0.24)	.216
	Erect	0.20 (0.14-0.29)	

In addition, a significantly lower effective dose was seen in the PA erect position for both the overweight ( $t=2.623$   $df=47$ ,  $p=.012$ ) and obese ( $t=4.475$   $df=61$   $p<.001$ ) categories but not the normal BMI group ( $t=1.701$   $df=26$   $p=0.101$ ) (Figure 5). The difference was also evident across the groups in relation to patient AP abdominal diameter (Figure 7). For the lateral effective dose there was no statistical significance across the different BMI categories (Figure 6).

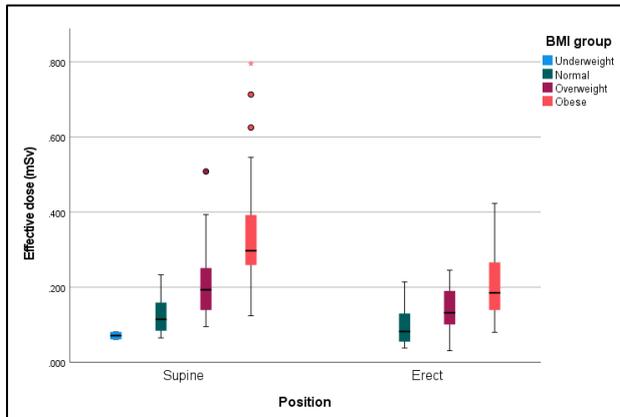


Figure 5: Comparison of effective dose by body mass index (BMI) category across AP supine and PA erect projections

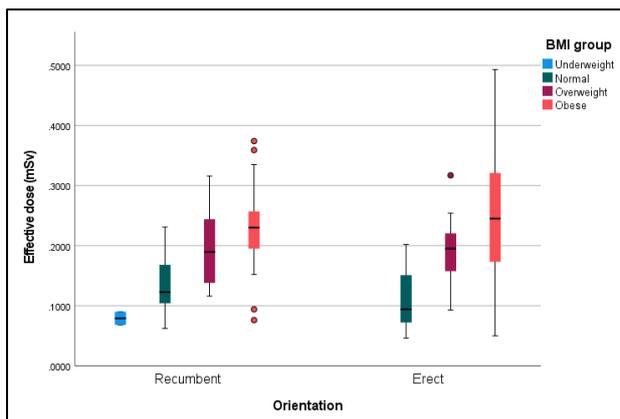


Figure 6: Comparison of effective dose by body mass index (BMI) category across lateral recumbent and erect projections

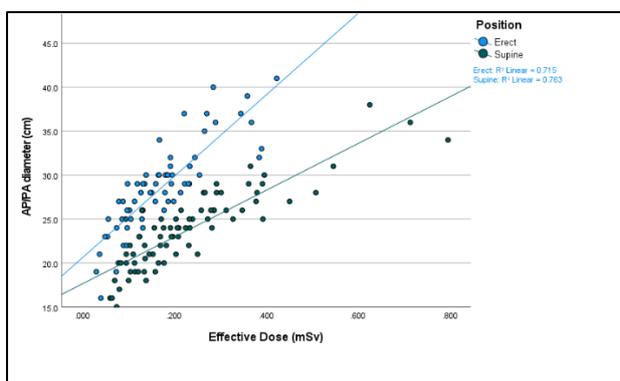


Figure 7: Variation in effective dose by patient abdominal diameter in the AP/PA orientation

Colon and testes doses were significantly higher in the supine AP projection ( $p<.001$ ) but not the lateral orientation (Table 3). No statistically significant difference was observed in the ovary dose between the erect and supine projections (Table 3).

Table 3: Organ specific doses across patient cohorts.

Organ	Projection	Number of patients	Orientation	Mean dose (mGy) $\pm$ SD	Significance ( $p$ )
Colon	AP	76	Supine	0.425 $\pm$ 0.261	<.001
	PA	66	Erect	0.207 $\pm$ 0.139	
	Lateral	76	Recumbent	0.336 $\pm$ 0.141	.156
		66	Erect	0.304 $\pm$ 0.151	
Ovaries	AP	54	Supine	0.379 $\pm$ 0.225	.127
	PA	45	Erect	0.307 $\pm$ 0.172	
	Lateral	54	Recumbent	0.204 $\pm$ 0.127	.684
		45	Erect	0.204 $\pm$ 0.108	
Testes	AP	22	Supine	0.040 $\pm$ 0.059	<.001
	PA	21	Erect	0.013 $\pm$ 0.024	
	Lateral	22	Recumbent	0.003 $\pm$ 0.003	.404
		21	Erect	0.005 $\pm$ 0.005	

## Discussion

When assessing the radiation dose implications of the two techniques, there are several factors which need to be considered, particularly in a non-controlled evaluation. Patient groups were similar in terms of gender and age, although the erect cohort did comprise patients with a higher BMI. The mean exposed area was slightly larger in the erect lateral projection but overall, there was no significant difference between the positions, therefore it should be considered that any variation in radiation dose was as a result in the change in patient orientation. Previous research has particularly focussed on the impact of moving from AP to PA positioning,<sup>16-20</sup> with no specific investigation of the dose implications of spinal radiographs in the erect position.

Mean DAP calculations were similar across patient AP/PA orientations, similar to Alukic et al,<sup>18</sup> although it is acknowledged that they utilised a prone orientation which will have resulted in a decrease in abdominal diameter as a result of compression which is reversed on standing.<sup>27</sup> Further, in our study the increase in erect SID will have had an impact on this metric. Other studies have demonstrated an effective dose reduction of between 19-53% between supine and prone techniques.<sup>16,18</sup> On average there was a 20% lower dose in the erect PA position even with the predominantly obese patient cohort and increased truncal diameter. In addition, dose to the colon was on average 65% lower, similar to previous prone based research.<sup>16</sup> In the lateral position, the DAP value was higher in the erect position, although the effective and organ doses were not significantly different. This is despite the larger patient cohort and likely influenced by the increased SID. Overall, the data would suggest that the DRLs in place for recumbent imaging would not be exceeded but it perhaps does support the potential of establishing additional levels based on patient orientation. Other techniques have been shown to reduce radiation dose, including the use of an air gap instead of a grid, lead shielding, collimation and higher tube potential (kVp)<sup>28</sup> with the latter both considered as part of this study. Future research will need to consider the potential of all dose reduction strategies within a larger patient cohort.

Maintaining diagnostic quality is critical in technique optimisation, this includes traditional image quality metrics such as anatomical inclusion and sharpness<sup>18</sup> but also includes the utility of the radiographs in terms of pathology demonstration. Radiographic texts<sup>29,30</sup> indicate that the PA projection enables better visualisation of the intervertebral disc spaces and sacro-iliac joints as a result of the alignment of the concave spine with the diverging beam. In the supine orientation the

low number of intervertebral disc spaces fully visualised, and hence clear vertebral anatomy, may have also been influenced by leg extension which exaggerates the lumbar lordosis.<sup>29</sup> In the lateral projection the improved quality may have been influenced by two factors, the increased SID and the impact of posture, with the hip width and shoulder width disparity causing tilt of the spine when recumbent, which would not occur when the patient is standing upright. Both these metrics need further investigation, particularly across a range of different pathologies and patient groups.

The clinical benefits of the change in protocol with the diagnostic advantage of the erect positioning. Similar outcomes have also been demonstrated with digital slot scanning (EOS), CT and MRI in relation to vertebral alignment, with axial loading often used to mimic weightbearing.<sup>31-33</sup> In our study the number of patients in the erect cohort with a measurable LLD was higher than anticipated. As it is not possible to demonstrate this in a supine orientation it perhaps explains the limited inclusion of such data in previous imaging studies across different imaging modalities. In our cohort there was correlation between LLD and spinal curvature and although the proportion of patients with scoliosis was small there remains the potential that this may be one of the underlying factors in development of low back pain, particularly with a difference of more than 2cm.<sup>34-36</sup> As such, the implications of the patient orientation at image acquisition is an important factor and must be considered by reporting radiologists and radiographers.

This study does have a number of limitations. The number of patients was relatively small and collated as convenience samples from a 2018 audit and 2020 evaluation project. No patient related quality of life assessment was made so it is unclear whether patients definitely had co-existing abnormalities affecting the hip or knee at the time of imaging. This would require clinical assessment/confirmation of leg length variation which may have been influenced by a range of factors including developmental anomaly, previous trauma and/or degenerative disease. As such, there is a need for prospective multicentre assessment using differing equipment and patient groups to provide truly generalisable findings. Quality assessment of the radiographs was not undertaken and future research should consider any repeat images, the deviation index and structured image review, however all examinations were considered adequate by the examining radiographer and of a diagnostic standard by the reporter. No attempt was made to ascertain whether there should be a limit on the suitability of the erect position for very large patients as there is an acknowledged link between decreasing image quality and increasing patient diameter in the pelvis and abdomen.<sup>27,37</sup> It is also worth noting that PCMXC data includes height and weight this does not fully reflect fat distribution, we have tried to account for this by also collecting the patient diameter.

## **Conclusion**

Despite strategies to reduce the number of lumbar radiographs performed referrals are still justified in certain clinical circumstances and this remains a common imaging examination. This single centre evaluation has confirmed clinical and radiation dose benefits from imaging the lumbar spine in an erect position. The results support the change in local protocol, but larger scale evaluation is required to optimise acquisition techniques across centres and patient groups.

Cross sectional modalities have been utilising axial loading strategies and are increasingly investigating patients in an erect, or simulated upright, stance, yet radiography practice has not changed. The identification of postural and functional abnormalities may influence patient management beyond what has been considered previously. Awareness of the differences in posture is critical to correctly acquire and interpret the images and educational strategies will be required to support widescale change in practice.

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