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Title Page

Please be upstanding – a narrative review of evidence comparing upright to supine lumbar spine MRI

Author names

Martin A. Baker (Corresponding Author)

m.baker@bolton.ac.uk

1. Faculty of Health and Wellbeing, University of Bolton, Deane Road, Bolton BL3 5AB.

2. Medserena Upright MRI Centre, 26 The Boulevard, West Didsbury, Manchester M20 2EU.

Stuart MacKay

School of Health Sciences, University of Liverpool, Brownlow Hill, L69 3GB

Please be upstanding –

a narrative review of evidence comparing upright to supine lumbar spine MRI

Structured Abstract

Objectives: The objective of the review was to examine the evidence comparing upright to supine MRI of the lumbar spine.
Key Findings: A literature search identified 14 articles comparing data where subjects had been scanned in both supine and upright positions on the same scanner.

Lumbar spine anatomy is dynamic and therefore subject to morphological changes when transitioning from the supine to the upright position. There is strong evidence to suggest structural changes in spinal morphology due to radiographic positioning, and that upright positioning is better for evaluating spondylolisthesis.

Conclusion: It has been demonstrated that the scanning position is important in the outcome of the MRI examination of the lumbar spine. With this in mind, it would be beneficial for guidance to be written and adopted to improve the consistency and quality of scanning.

Implications for practice: As upright MRI occupies a niche in the scanning sector, many professionals are unaware of its capabilities. This article aims to increase awareness of the use of upright MRI in evaluating the lumbar spine.

Please be upstanding – a narrative review of evidence comparing upright to supine lumbar spine MRI

Introduction

With conventional MRI the patient's upper body weight is not incumbent upon the spine as it would be in the upright position. The configuration of the spine is known to change with body position due to the effects of gravity[1,] meaning some patients' clinical symptoms are demonstrably present or exacerbated in the upright position. Consequently, it has been recognised that some gravity-dependent pathology may be underestimated using conventional MRI [2,3]. Upright projection radiography has been used for investigation of a number of lumbar spine parameters including neuroforaminal and spinal stenosis[2] and scoliosis[4]. Upright myelography has also been used effectively to demonstrate dynamic changes in the dural sac[5]. Three-dimensional evaluation of the lumbar anatomy is not achievable with conventional projectional radiography, meaning supplementary MRI and CT may be needed. Previous MRI studies have simulated the effects of gravity on the lumbar spine using axial loading in the supine position [3,6]. However axially loaded scans do not properly consider the weight of the upper body or the effects of muscle activation on the stability of the spine[6]. The advent of the upright MRI scanner has added an extra dimension to the diagnostic capabilities of MRI, in that patients can be scanned in a more natural weight-bearing position. Upright MRI is still a relatively new technique and there are very few imaging centres in the UK offering upright scanning compared to standard MRI [7]. There are also currently no international recommendations relating to the use of upright MRI [8]. The objective of this review was to evaluate the impact of radiographic positioning (supine vs upright) when examining the lumbar spine using open low-field strength MRI systems.

Methods

A narrative review methodology was adopted to capture both qualitative and quantitative data relating to the role of upright MRI. An electronic literature search was carried out on 4th January 2020 to identify relevant articles, employing key words related to two domains: upright MRI and the lumbar spine. Combinations of the following search (keyword and MeSH) terms were used: 'upright' OR 'open' OR 'weight-bearing' AND 'MRI' OR 'magnetic resonance imaging' AND 'lumbar'. The search was conducted on PUBMED, CINAHL and SPRINGER LINK electronic databases. Date ranges were 2009-2019 inclusive. Appropriate subject headings and word truncations were used for each electronic database. Titles and abstracts of the initial results were screened for suitability by one reviewer (insert initials here).

Study selection

Only English-language studies were included. The primary factor for inclusion was that subjects had to have been scanned in both supine and upright positions, using the same scanner. Hence a direct comparison between the two positions was achievable. Case reports and literature reviews were excluded. Articles were evaluated using the Critical Appraisal Skills Programme (CASP) tool for diagnostic tests to ensure suitability for inclusion[9].

Results

The electronic database search generated 422 articles in Pubmed, 44 in CINAHL and 126 in Springer Link. One hundred and forty-six potentially eligible articles were then selected based on title and abstract. Full text screening further refined the search based on quality and relevance, leading to 14 articles being included in the review. The Preferred Reporting Items for Systematic Review (PRISMA) chart (figure 1) details the search procedure[10].

Our literature search indicated that the low field-strength MRI scanners with the capability to scan in both the supine and upright positions were the 0.25T Esaote G-scan (Esaote, Genoa, Italy), the 0.6T Fonar Indomitable (Fonar Corporation, Melville, NY, USA) and the 0.5 T Paramed MrOpen (Paramed Medical Systems, Genova, Italy). Most upright scans were performed at an angle of just less than 90° to reduce stability problems of the patient [11]. All upright scans were performed in the standing position with the exception of one which was performed sitting. (Table 1).

Findings were then categorised according to pathology, anatomical region or position, and are discussed below.

Lumbar lordosis

Being a dynamic structure, the lumbar spine adapts its shape according to body position and loading. Measurement of the lumbar lordosis angle (LLA) (figure 2) is an important factor when interpreting spinal anatomy [12], as increased lordosis is associated with increased pain sensation [7]. The review found inconsistencies in the landmarks used to measure the LLAs, which was partly a result of the smaller field of view available on the Esaote G-scan (table 1). As a result, evaluation of shorter lengths of spine would be expected to underestimate lumbar lordosis angles. Table 1 describes mean findings relating to LLA and whether subjects being scanned had pre-existing conditions or if they were asymptomatic.

A significant increase of around 6° (range 6.0°-6.8°) in lumbar lordosis angle upon transition from supine to the upright position was found in four studies [8, 11-13]. Hansen et al [13] discovered that patients with lower back pain exhibited significantly less lordosis in both the upright (-5.6°) and supine positions (-6.4°) compared to healthy controls.

Only two papers found the LLA did not differ significantly between supine and standing positions [14,15]. One of these had a very small number of subjects (n=6), making the results less reliable[14]. The other was the only study where subjects were scanned in the 90° upright position, which could potentially have an influence on findings because leaning backwards leads to extension of the spine[15].

A single article reported a small but significant decrease in LLA on standing [16], and also examined anterior to posterior disc height ratios. The same study found anterior to posterior height ratios at L2/3 and L3/4 increased significantly, whereas the L5/S1 ratio decreased significantly on standing in healthy subjects, again showing a decrease in lordosis [16]. Of particular note is the use of young healthy adult subjects in this case.

The only investigation using a sitting, upright position found mean lordosis angles of 23.2° in the sitting position and 53.4° in the supine position but no statistical analysis was performed [17]. This figure was broadly comparable to another sitting MRI study which had a LLA of 29° [18].

Splendiani et al [19] considered the LLA to be altered if it differed from a previously published physiological value of 50°, but did not state by how much the difference needed to be. Fifty nine percent of patients were considered to have a decreased LLA in both positions, and 19 % of patients had an increased LLA. In a later study Splendiani et al [20] recorded changes in the lumbar lordosis if greater than ten degrees between the two positions. This was unusual given that a change of around six degrees was considered statistically significant in much smaller studies [11,12]. In total 69% of patients demonstrated a change of greater than ten degrees, but there was no indication as to whether this covered increases or decreases in LLA. These findings also raise the question of whether mean values are the best method for describing changes in a variable population, and more research may be required in this field to determine whether this is the case.

Lumbosacral angle

The lumbosacral angle (LSA) also gives an indication of the degree of lumbar lordosis. A more vertically angled sacrum results in more loading on the anterior aspect of the spinal column, and vice versa[11]. Increased anterior loading is associated with L5-S1 disc degeneration, whereas posterior loading adversely affects the facet joints [11]. Tarantino [11] found that the mean LSA of patients experiencing lower back pain changed by 5° when moving from the supine position to the upright position. This was considered statistically significant, and indicated an increase in the degree of lumbar lordosis. Similarly Kubosch et al [2] measured the mean LSA at 49.4° in supine, and 55.8° in the upright position, again showing increased lordosis in the upright position. However it was not clear how this angle was measured and no statistical support was given to indicate significance. Moreover, these patients were previously diagnosed with L5/S1 spondylolisthesis and so could not be considered representative of the population as a whole.

In contrast Weber et al demonstrated a significant decrease in lordosis at the L5/S1 angle of healthy volunteers [16]. Importantly this was the only disc level in the lumbar spine found to vary significantly between positions. This was consistent with the LLA which also decreased on standing for these patients. Unlike other researchers, Splendiani et al[19] did not compare average LSA angles between groups. They did find that 53% of patients had a lumbosacral angle greater than a pre-defined normal range of 120-135°. Although this appears to be an important finding, no discussion was made regarding the validity of the range used.

Methods used to describe lumbosacral angle are detailed in table 2.

Spondylolisthesis

Spondylolisthesis is defined as the anteroposterior displacement of vertebrae, and may lead to progressive vertebral bony deformity and compression of adjacent nerves [21]. The degree of spondylolisthesis is expressed on a scale of 1 to 5, with 5 being the greatest [21]. Splendiani et al's study of 4305 lower back pain patients found that 9.5% demonstrated spondylolisthesis in the upright position only, which was termed 'occult spondylolisthesis'[20]. Similarly a smaller study reported no spondylolisthesis in the supine position, but a grade I spondylolisthesis was found in 10% of patients when upright [15]. This incidence appears conservative compared to previous literature which showed spondylolistheses in 18% [22] and 28% [23] of patients using upright radiographs compared with supine MRI. Only one author in this review [8] found no difference in the number of spondylolistheses visualised in upright vs supine scanning in patients with lower back pain.

A number of studies examined patients with known spondylolistheses, providing a further dimension to the understanding of the weight-bearing position on this condition. In a sample of ten patients due for L4/5 interbody fusion, including nine cases of spondylolisthesis, a slight increase in sagittal translation was noted but it was not considered significant[7]. However, it is probable that the spondylolistheses in these cases were initially diagnosed and selected using supine imaging, which would explain the results.

Four out of twenty-nine patients with spondylolisthesis visible on supine images showed worsening of spondylolisthesis in the upright position, but no new instances were found in the remaining patients [11]. In patients with known spondylolisthesis of L5/S1 the mean intervertebral translation at this level was found to be 8.3mm in the supine and 9.9mm in the upright position. However, this small difference was not considered statistically significant[2].

It is evident that more information regarding the presence and degree of lumbar spondylolisthesis is obtained during upright MRI. There is a subgroup of patients for which upright scanning would be beneficial where previous imaging has failed to find the cause of the clinical problems. The clinical significance of this is high because spondylolisthesis of over 3mm can be considered unstable [17].

Disc morphology

Lumbar intervertebral discs are subjected to a fivefold increase in pressure in the standing position compared to supine [24]. With the spine being a dynamic structure it is important to understand the effects of different positioning has on the relevant anatomy. Splendiani et al [25] measured the anterior, middle and posterior sections of the intervertebral discs from L1-S1 in both positions. Mean disc height was reduced in 35/38 patients when in the upright position, with a significant difference in disc height change. Shymon [14] examined the lumbar spine of six healthy volunteers in the supine and upright position. The anterior height of the only disc evaluated (L5-S1) was found to be significantly smaller in the upright position compared to the supine position. The maximum disc height at the L3/4 level was measured by Tarantino et al [11]. The mean was significantly reduced in the upright position by 1.7mm, with male subjects' discs being significantly thicker than those of females. Intervertebral disc width was only examined in one publication, and was not found to differ between positions in healthy subjects [16]. These results are important as the Intervertebral height is a factor associated with nerve compression in intervertebral foraminae[2].

Disc protrusions, when orientated towards the spinal canal or intervertebral foramen, can potentially compress the spinal cord and nerve roots. Splendiani et al [20] found that the appearance or Increase of disc protrusions when upright compared to supine was statistically significant. Notably, eleven percent of patients had a disc protrusion only apparent when upright. Another author found the mean extent of disc bulging increased significantly when in upright position[15]. A significant volumetric increase of disc protrusions was seen in the upright by Tarantino et al [16], with 11/53 patients showing disc protrusions which were not present in the supine scan.

As a measure of disc degeneration, Hansen et al [13] graded all lumbar disc levels on a scale of 1-5, to give an overall lumbar disc disease (LDD) score. The LLA was not seen to correlate to the LLD score in either the upright or supine position. Changes in LLA correlated negatively with the LDD score in healthy volunteers but not for lower back pain patients.

Disc morphology is therefore subject to change when in the upright position. Upright scanning demonstrates a greater extent of disc pathology that could result in nerve compression, and which is not evident in the supine position.

Neural dimensions

Variation in a range of dimensions has been investigated, including AP diameter of spinal canal, dural sac dimensions and neuroforaminal diameters. There is clearly an overlap with changes in these parameters and changes in disc morphology, and indeed lumbar lordosis. Splendiani et al [19] analysed two lumbar disc levels per patient: a clinical symptomatic level and a clinically non-pathological control. One hundred and fifteen patients were studied. In total 61/230 disc levels showed stenoses only on upright scanning. Every one of these occult stenoses occurred in a different patient, and correlated with clinical symptoms which worsened in the upright position. On the other hand, Hansen [8] studied the L2/3 to L5/S1 disc levels for stenoses, and found no difference in the number of spinal stenoses upon changing position. The reason for the difference in findings between the two studies is not clear, as both studies were performed using the same scanner on patients with lower back pain. However, Hansen et al[8] did note only fair-to-moderate inter-and intra-reader reliability between their three readers. This aspect would therefore warrant further investigation.

Neuroforaminal diameter

The neuroforamen is anatomically important as it is the passage through which nerves pass on exiting the spinal canal. The mean foraminal area and diameter at L4/5 were shown in one study to decrease significantly by 13% and 10% respectively from supine to upright[7]. Mauch et al [12] investigated level 1 narrowing of the neural foraminae and found it more pronounced in 13.4% of patients at L4/5 and 26.7% of patients at L5/S1. At the L5/S1 level another study found these measurements to be decreased on standing, but not significantly[2]. Variations in results of these studies may be attributed to sampling error when measuring such small dimensions or the small study sizes.

Spinal canal dimensions

Posture-dependent variations in the spinal canal were observed in a number of studies. Anteroposterior (AP) diameters of the lumbar spine anatomy have been measured as dural sac diameter [16] or spinal canal diameter/stenosis [19,20]. Splendiani [20] discovered that 9.2% of patients with back pain demonstrated spinal canal stenosis in the upright position which was not seen in the supine position. In a separate study the mean spinal canal diameter was observed to decrease by 13.1% in the upright position [15]. The maximum AP diameter of the dural sac was also found to decrease significantly when upright at L3/4 and L4/5 by Mauch et al [12], but not at L5/S1. Similarly the mean dural sac diameter reduced significantly by 13.1% on standing in the study by Muto et al [15]. The dural sac cross-sectional area (DSCA) was found to increase by a non-significant amount on standing by Mauch et al [12], whereas the spinal canal cross-sectional area (SCCA) did not change.

The volume of the central canal at L4/5 was measured by Lang et al [7], and seen to decrease by 8% in the upright position, although not significantly. In another paper however, volume measurements at L5/S1 increased when upright, but not reaching significance[2]. After repeatedly changing position from supine to upright the authors then noted a reduction in spinal canal volume, although no data was presented to verify this.

Patients with neurogenic claudication were studied by Lau et al [26]. Dural sac cross-sectional areas (DSCA) and sagittal AP dimensions at the most constricted lumbar spinal level on supine MRI were compared to their corresponding standing position. Mean DSCA and AP diameter were found to be significantly reduced in the standing position (by 28.7% and 25.4% respectively). Upon correlation of DSCA and sagittal AP dimensions with distance where claudication was experienced, upright MRI showed significantly better correlation than supine MRI. Upright MRI also demonstrated significantly better correlation of dural sac parameters with visual analogue score (VAS) of leg pain than supine

MRI. This was in agreement with another study on neurogenic claudication, which demonstrated dural sac diameter, spinal canal diameter and spinal canal areas decreased significantly when upright [16].

Only one set of results showed a significant increase in mean AP dural sac diameter on standing. The maximum AP diameter of the dural sac at L3/4 increased from a mean of 13.1mm to 14.5mm on standing, with no differences between genders observed [16].

It has therefore been demonstrated that in general spinal canal dimensions reduce in the upright position, showing greater potential to identify problematic pathology and nerve compression.

Juxtafacetal cysts and facet joint effusions

Nerve root compression and spinal canal stenosis can be caused by juxtafacetal cysts in the same way as disc protrusions [17]. Supine MRI scanning has not been able to reliably identify all juxtafacetal cysts when compared retrospectively to pathological examination[27]. With this in mind Niggemann et al [17] studied fifty patients diagnosed with intraspinal or intraneuroforaminal juxtafacetal cysts. It was found that the detection rate for juxtafacet cysts was 89% for supine scanning but only 78% for the upright neutral sitting position. These findings were attributed to a reduction in lordosis in the neutral sitting position compared to the supine and extended positions. This was mirrored by another study, where the majority of facet joint effusions visualised on supine imaging were considered to disappear on standing [8].

Limitations

Limitations to the research include the small study size of many of the papers and their associated power and generalizability to the overall population. This review only analysed papers from three databases and therefore is likely to have excluded some relevant publications. Only one author searched and reviewed the papers and it would have been preferable to have had a larger team to do this.

The physical dimensions of the Esaote G-scan created two problems. Firstly the limited field of view made it difficult to examine the full length of the lumbar spine on studies using this scanner. Secondly, there was a limitation on the antero-posterior dimensions of patients which could be accommodated within this model of scanner.

Variations in results could have been influenced by the lack of uniformity in positioning for the supine scanning, with some researchers using the extended leg position, and others using a bolster under the lower legs to achieve a psoas relaxed position. Other factors affecting the LLA could include upright scanning angle, measurement technique and patient health status. Although the LLA measurements were generally consistent with a previously described method [28], it is acknowledged that it has high inter- and intra-observer variations compared with other methods [29].

Differences in protocols and methods varied across studies. A lack of standardisation in methods and measurement techniques must therefore be acknowledged. In addition no study noted how many radiographers were involved in each study, or how experienced they were. This could have had an effect on the consistency of positioning.

Lastly, the effects of flexion and extension scans (or hyperlordosis position), or of load-carrying positions in the upright position were not considered in this review, and would make a suitable topic for further review.

Conclusions

Lumbar spine anatomy is dynamic and therefore subject to morphological changes when transitioning from the supine to the upright radiographic position. There is strong evidence that disc morphology and pathology varies according to radiographic position, and that upright positioning is better for evaluating spondylolisthesis. Furthermore it has been demonstrated that the scanning position is important in the outcome of the MRI examination of the lumbar spine. With this in mind, it would be beneficial for guidance to be written and adopted to improve the consistency and quality of scanning.

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Figure 2

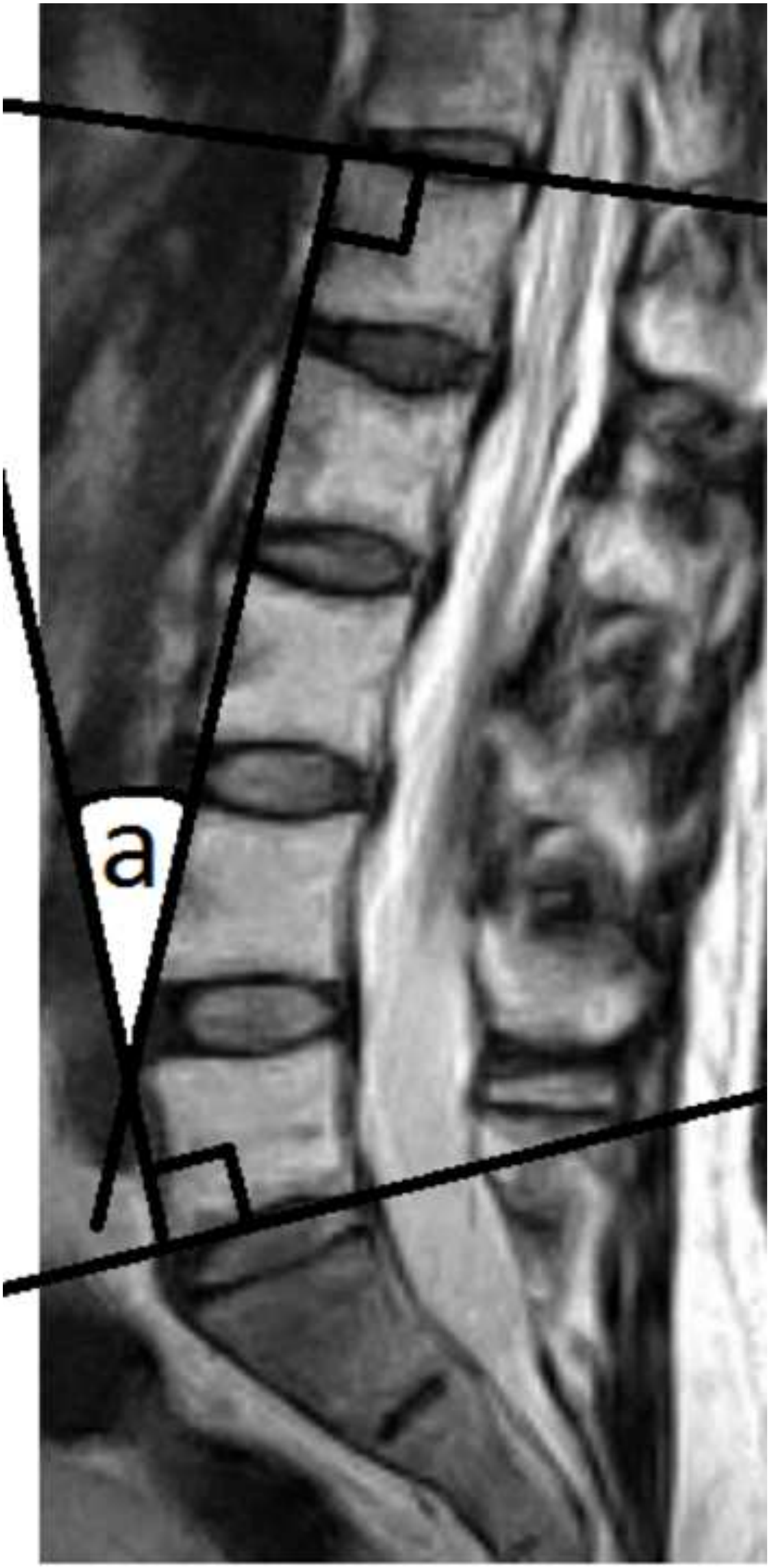

Figure 1 - PRISMA chart

Figure 1: PRISMA flow diagram for search results

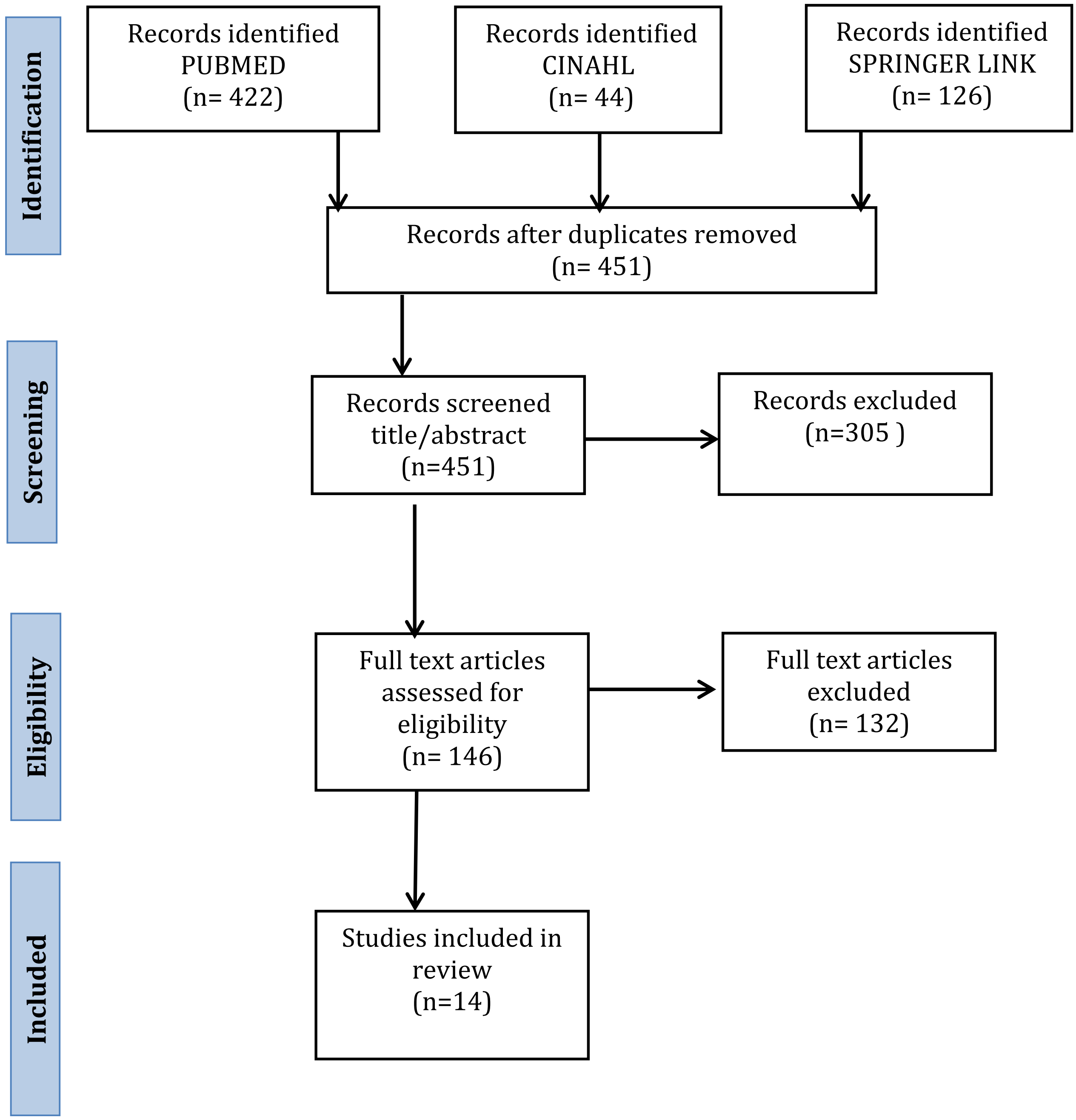

Figure 2.

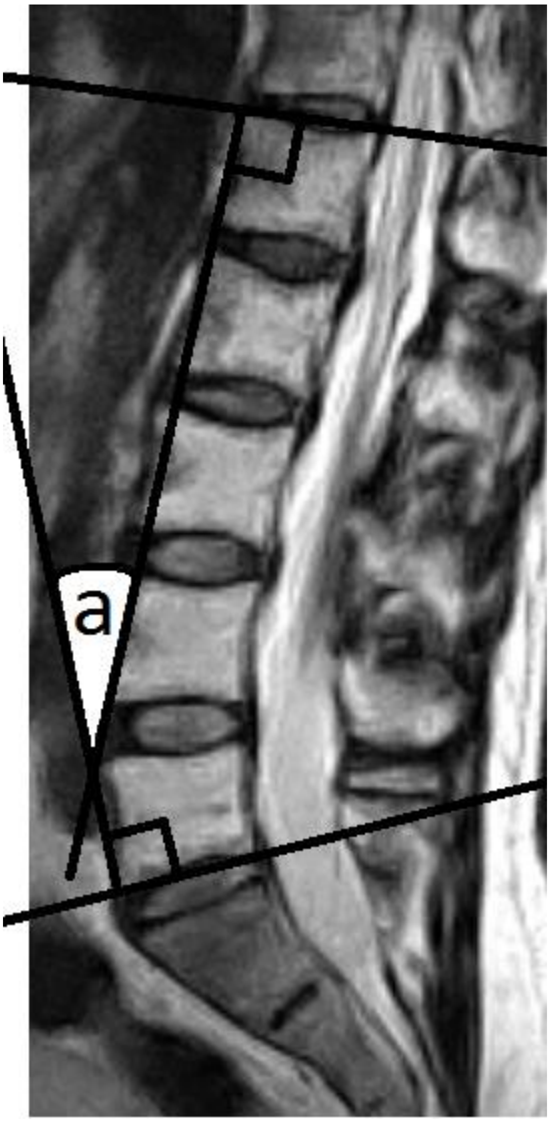

Figure 2: Measurement of the lumbar lordosis angle. The lumbar lordosis angle a is calculated by tracing tangents to the upper endplate of L1 and the lower endplate of L5, and measuring the angle formed by the intersection of two lines perpendicular to the tangents

Tables 1-2

Study	Scanner	Subject presentation	N	Upright position		Lumbar lordosis angle measurement	Mean LLA supine	Mean LLA upright	Difference
Hansen et al 2015	0.25T Esaote	Lower back pain	38	82º	Standing	Superior margins of L2 and S1	45.6º	52.4º	6.8º
Hansen et al 2015	0.25T Esaote	Healthy control group	38	82º	Standing	Superior margins of L2 and S1	52º	58º	6º
Hansen et al 2018	0.25T Esaote	Lower back pain	56	82º	Standing	Superior margins of L2 and S1	43.7º	50.3º	6.6º
Kubosch et al 2015	0.25T Esaote	Chronic back pain	15	80º	Standing	Not performed	***	***	***
Lang et al 2018	0.25T Esaote	Lumbar degenerative disorders	10	80º	Standing	Not performed	***	***	***
Lau et al 2017	0.25T Esaote	Neurogenic claudication	70	84º	Standing	Not performed	***	***	***
Mauch et al 2010	0.25T Esaote	Healthy athletes	35	*	Standing	Superior margins of L2 and S1	46.3º	52.6º	6.3º
Muto et al 2016	0.5T Paramed	Neurogenic claudication	40	90º	Standing	Superior margins of L1 and S1	51.3º	53.3º	2º
Niggemann et al 2012	0.6T Fonar	Various symptoms	32	*	Sitting	Superior margins of L1 and S1	23.2º	53.4º	30.2º
Shymon et al 2014	0.6T Fonar	Healthy	6	84º	Standing	Superior margins of L1 and S1	55º	57º	-2º
Splendiani et al 2014	0.25T Esaote	Lumbosacral pain	160	*	Standing	Superior margins of L1 and inferior margin of L5	***	***	***
Splendiani et al 2016	0.25T Esaote	Lower back pain	4305	82º	Standing	Superior margins of L2 and inferior margin of L5	***	***	***
Splendiani et al 2019	0.25T Esaote	Lower back pain	38	82º	Standing	Not performed	***	***	***

Tarantino et al 2013	0.25T Esaote	Lower back pain on standing	53	82°	Standing	Superior margins of L1 and inferior margin of L5	35.5	41.6	6.1*
Weber et al 2019	0.6T Fonar	Young healthy adults	40	84°	Standing	Inferior margin of T12 and superior margin of S1	53.4	50.6	-2.8 *

Above: Table 1. Summary of studies.

*** information not provided

	Sample size	L5/S1 angle calculation	Mean angle supine	Mean angle upright	Mean effect on lordosis when upright
Kubosch et al 2015	15	Not described	49.4°	55.8°	Increase
Splendiani et al 2014	115	Tracing two lines parallel to front profile of body of L5 and S1	n/a	n/a	None shown
Tarantino et al 2013	53	Anterior open-angle intercepted by two tangent lines of the anterior walls of L5 and S1	136.7°	131.7°	Increase
Weber et al 2019	40	Segmental Cobb angle	12.0°	9.52°	Decrease

Above: Table 2. Lumbosacral angle measurements.