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Review article

Sagittal balance in sitting and standing positions: A systematic review of radiographic measures

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ABSTRACT

Background: Sagittal imbalance can be caused by various etiologies and is among the most important indicators of spinal deformity. Sagittal balance can be restored through surgical intervention based on several radiographic measures. The purpose of this study is to review the normal parameters in the sitting position, which are not well understood and could have significant implications for non-ambulatory patients.
Methods: A systematic review was performed adhering to PRISMA Guidelines. Using R-software, the weighted means and 95% confidence intervals of the radiographic findings were calculated using a random effect model and significance testing using unpaired t-tests.
Results: 10 articles with a total of 1066 subjects reported radiographic measures of subjects with no spinal deformity in the sitting and standing position. In the healthy individual, standing sagittal vertical axis −16.8°was significantly less than sitting 28.4° ($p < 0.0001$), while standing lumbar lordosis 43.3°is significantly greater than sitting 21.3° ($p < 0.0001$). Thoracic kyphosis was not significantly different between the two groups ($p = 0.368$). Standing sacral slope 34.3° was significantly greater than sitting 19.5° ($p < 0.0001$) and standing pelvic tilt 14.0° was significantly less than sitting 33.9° ($p < 0.0001$).
Conclusions: There are key differences between standing and sitting postures, which could lead to undue stress on surgical implants and poor outcomes, especially for non-ambulatory populations. There is a need for more studies reporting sitting and standing radiographic measures in different postures and spinal conditions.

1. Introduction

The sagittal balance of a patient plays an important role in the health of the spine and is an indicator of the severity of spinal deformity [1–3]. Sagittal imbalance can be caused by various etiologies such as ankylosing spondylitis, degenerative conditions, and

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Abbreviations: SVA, sagittal vertical axis; PT, pelvic tilt; SS, sacral slope; PI, pelvic incidence; TK, thoracic kyphosis; LL, lumbar lordosis; CL, cervical lordosis; NOS, Newcastle Ottawa Scale; CI, confidence interval.

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traumatic injury. It can lead to pain and difficulty with ambulation [4]. A goal of spinal deformity correction surgery is to restore sagittal balance guided by radiographic measurements in order to achieve optimal clinical improvements. Using standing radiographs, the standard modality, sagittal vertical axis (SVA), pelvic tilt (PT), sacral slope (SS), pelvic incidence (PI), thoracic kyphosis (TK), and lumbar lordosis (LL) are commonly measured for reference [5].

SVA is a measure of global spinal balance and represents the distance between a C7 vertical plumb line and the superior posterior corner of S1 [5]. A positive sagittal balance passes >2 cm in front of the superior posterior corner of S1 with >5 cm being abnormal [4,5], and while this method is not without criticism [5,6], it has been correlated with clinical symptoms [4]. PT is the magnitude in which the pelvis rotates around the femoral heads while SS characterizes the S1 endplate position and these values comprise PI (PI = PT + SS) which is anatomically fixed, specific for each individual, and solidified after adolescence [5,7]. Realignment of the lumbar spine to PI has been shown to improve outcomes [8,9], and PT and SS are clinical predictors as well [5,10–12]. LL has typically been measured from L1-S1 while TK varies but is generally measured from T1-12 or T5-12. The inflection point, which is the transition from TK to LL, has traditionally been T12-L1, but is now known to vary based on PI [7,13]. The SRS-Schwab classification [14], uses coronal curve type and a combination of the above radiological measurements including a PI-LL modifier, PT modifier, and global balance SVA modifier to plan for spinal surgery and has been correlated to health-related quality of life [5,15].

Changes in lifestyle, technology, environment, and population age have led to a considerable increase in time spent in the sitting position. There is a paucity in the literature regarding normal parameters in the sitting position, especially among non-ambulatory patients. The impact on lumbar alignment and pelvic compensation in sagittal balance has not been fully defined [16–19]. For example, there is spinal straightening and pelvic retroversion upon sitting [20,21] owing to a general decrease in LL and an increase in PT [22,23]. This would indicate that spinal fusion based on standing sagittal radiographs alone would place the spine under undue stress in the sitting position [3,20]. Despite this, standing radiograph remains the standard for determining severity and approach to spinal deformity [13,18,24].

Recently, studies in populations of total hip arthroplasty [25–33], adult spinal deformity [34], lumbar degenerative diseases [18,19,22], and lumbosacral fusion [23,35] have begun to employ standing versus sitting radiographic analysis with several groups showing significant differences in these classic radiographic measurements. However, these studies primarily look at the difference in measurements from sitting to standing and correlate to disease severity or pre- and post-operation. Studies in healthy populations are now emerging that show significant changes in measures between sitting and standing radiograph markers that may even be influenced by age, gender, and other modifications in body position [3,12,17,20,36–40]. Additionally, work is being performed in the artificial neural network space to predict sitting measures based on standing radiographs to inform surgical correction [41–43]. Therefore, the goal of this review is to understand the literature discussing sitting radiographs to be able to create a more informed approach to evaluating surgical goals.

2. Methods

A systematic review was performed adhering to PRISMA Guidelines (Fig. 1). The PUBMED, MEDLINE, Scopus, Cochrane, Web of

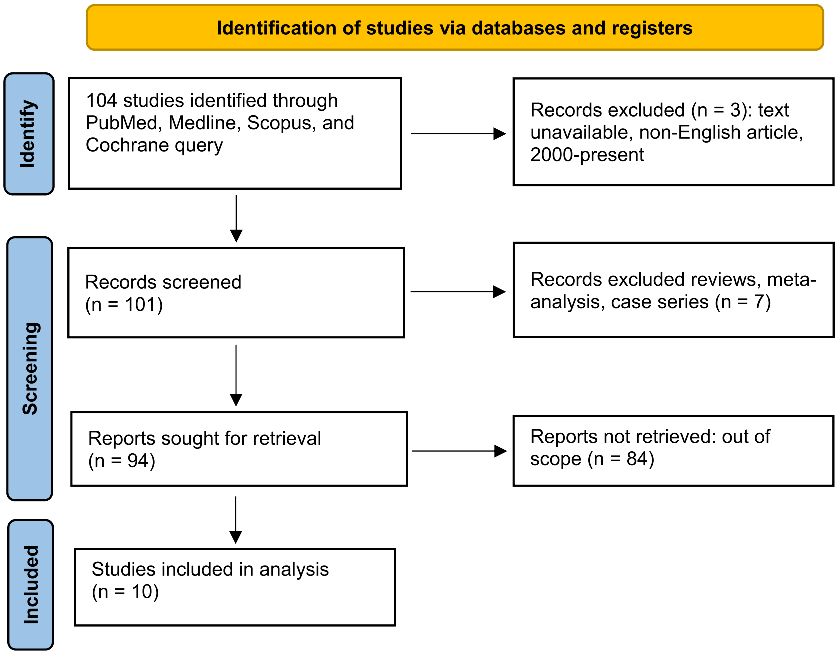

Fig. 1. Primsa flowchart.

Science, and Google Scholar databases were searched for studies describing radiographic measures following sitting radiographic imaging. The keywords “sitting”, “standing”, “sagittal alignment”, and “sagittal balance” were used. All studies, since 2000, with radiographic outcomes for normal or healthy controls were included. The outcomes that were of interest included: sagittal vertical axis (SVA), thoracic kyphosis (TK), lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), and pelvic incidence (PI). Meta-analyses, systematic reviews, and other literature reviews were excluded but utilized for citation matching for studies that met our inclusion criteria. Exclusion criteria were based on the scope of the article and limitations in data. Using *R-software*, the weighted means and 95% confidence intervals (CI) of the radiographic findings in the normal or healthy group were calculated using a random effect model with the *metamean* package. The data are presented as *mean [95% CI]*. Unpaired t-tests were used to determine significant differences between standing and sitting groups. For age, the t-score of the Pearson correlation coefficient for each radiographic measure. For all these non-randomized studies, the Newcastle Ottawa Scale (NOS) was used for quality assessment [41].

3. Results

3.1. Characteristics of included trials

We gathered radiographic data from the literature that presented normal spinal measurements [3,36–38,40,42,44–47]. Ten articles were found to publish sitting and standing radiographic measures with a total sample size of 1066 subjects. The quality assessment for each study is presented in Supplementary Table 1. The median age of all studies was 34.4 years old.

3.2. Sagittal radiographic measures

From the random effects model, in the normal or healthy individual, we found that standing SVA (−16.8 [−32.7; −0.8]) was significantly less than sitting SVA (28.4 [17.4; 39.5]), $p < 0.0001$. Standing LL (43.3 [38.0; 48.5]) is greater than sitting LL (21.3 [16.8; 25.8]), $p < 0.0001$. Standing TK was not significantly greater than sitting TK, $p = 0.368$.

3.3. Pelvic radiographic measures

Standing PI (47.2 [46.3; 48.0]) and sitting PI (47.3[43.7; 50.9]) are not significantly different, $p = 0.9114$. For the pelvic radiographic findings, standing SS (34.3 [32.9; 35.7]) was significantly greater than sitting SS (19.5 [16.9; 21.9]), $p < 0.0001$. Standing PT (14.0 [11.0; 17.0]) was significantly less than sitting PT (33.9 [27.4; 40.5]), $p < 0.0001$. (Tables 1–3).

3.4. Age

Using a Pearson correlation coefficient, we found that standing SS ($r(9) = -0.81$, $p = 0.002$), standing PT ($r(11) = 0.69$, $p = 0.008$), and sitting LL ($r(13) = 0.60$, $p = 0.03$) were the radiographic measures to have a significant correlation of radiographic measure with age. There were insufficient number of studies to properly evaluate the correlation of age with SVA and sitting PI.

4. Discussion

Sagittal spinal deformities are typically measured via a standing profile. Radiographic findings are measured via a 36 cm standing

Table 1
Sagittal radiographic outcomes for normal group.

Author	# Patients	Age mean (SD)	Standing mean (SD)			Sitting mean (SD)		
			SVA	TK	LL	SVA	TK	LL
Zhao et al., 202242	145	23.1 (2.3)	−20.1 (22.4)	26.1 (10.2)	50.4 (10.0)	26.9 (10.2)	20.0 (8.9)	25.3 (11.8)
Zhou et al., 20203	140	23.2 (2.6)	−20.5 (20.8)	26 (10.3)	50.5 (9.4)	25 (26.3)	20.1 (8.7)	25.5 (11.6)
Zhou et al., 20203	95	53.3 (6.2)	−9 (25.4)	34 (9.6)	51.7 (10.5)	33.7 (21)	29.3 (10.2)	38.3 (11.6)
Nishida et al., 202044	113	45.2	–	24.1 (8.4)	35.6 (9.6)	–	22.8 (8.2)	–
Maekawa 201945	105	33.3 (8.4)	–	–	49.3 (14.2)	–	–	23.3 (13.4)
Maekawa 201945	80	61.6 (5.4)	–	–	40.8 (11.5)	–	–	24.9 (16.2)
Maekawa 201945	68	75.6 (4.6)	–	–	42.1 (14.1)	–	–	27.1 (14.8)
Chevillotte 201846	15	42.9	–	–	54.8 (9.8)	–	–	15.9 (14.6)
Suzuki et al., 201838	25	26.9 (6.3)	–	–	31.9 (10.4)	–	–	7.9 (10.8)
Suzuki et al., 201640	73	34.4 (8.1)	–	–	31.3 (10.4)	–	–	15.5 (10.1)
Suzuki et al., 201640	107	67.6 (8.3)	–	–	26.6 (12.8)	–	–	16.0 (13.9)
Cho et al., 201547	30	31.1 (1.9)	–	–	47.1 (0.5)	–	–	17.7 (4.4)
Lee et al., 201437	10	25.4 (2.3)	–	–	52.8 (7.9)	–	–	13.5 (11.6)
Lee et al., 201437	10	66.7 (1.7)	–	–	53.9 (15.9)	–	–	27.9 (9.3)
Endo et al., 201236	50	31.5 (7.4)	–	–	33.3 (11.2)	–	–	16.7 (11.2)
Weighted Average (mean [95% CI])			−16.8 [-32.7; −0.8]	27.5 [20.6; 34.5]	43.3 [38.0; 48.5]	28.4 [17.4; 39.4]	23.0 [16.1; 29.9]	21.3[16.8; 25.7]

Table 2
Pelvic radiographic outcomes for normal group.

Author	# Patients	Age mean (SD)	Standing mean (SD)			Sitting mean (SD)		
			SS	PT	PI	SS	PT	PI
Zhao et al., 202242	145	23.1 (2.3)	34.9 (7.1)	11.8 (6.5)	46.6 (9.1)	19.7 (8.7)	28.4 (10.0)	48.0 (9.1)
Zhou et al., 20203	140	23.2 (2.6)	35.4 (7)	11.9 (6.2)	47.2 (9)	19.7 (8.5)	28.1 (9.9)	–
Zhou et al., 20203	95	53.3 (6.2)	34.3 (8.8)	14.2 (7)	48.6 (9.7)	28.2 (9.3)	20.4 (10.4)	–
Nishida et al., 202044	113	45.2	32.6 (8.3)	14.4 (7.3)	47.0 (9.25)	16.6 (9.4)	65.17 (8.24)	–
Maekawa 201945	105	33.3 (8.4)	34.6 (7.7)	19.7 (16.4)	–	18.1 (10.1)	32.5 (12.7)	–
Maekawa 201945	80	61.6 (5.4)	31.3 (8.5)	22.2 (15.1)	–	18.8 (10.1)	33.3 (14.0)	–
Maekawa 201945	68	75.6 (4.6)	31.6 (8.9)	24.3 (15.8)	–	20.1 (9.6)	33.2 (14.7)	–
Chevillotte 201846	15	42.9	37.1 (6.3)	12.1 (6.3)	49.3 (8.1)	11.3 (10.8)	37.7 (10.4)	48.7 (7.9)
Suzuki et al., 201640	73	34.4 (8.1)	36.4 (7.2)	10.3 (7.3)	–	19.0 (9.7)	27.6 (10.5)	–
Suzuki et al., 201640	107	67.6 (8.3)	32.6 (8.6)	15.3 (7.3)	–	21.2 (10.9)	27.5 (10.9)	–
Lee et al., 201437	10	25.4 (2.3)	–	8 (2.2)	45 (7.1)	–	40.3 (10.9)	–
Lee et al., 201437	10	66.7 (1.7)	–	11.4 (7.2)	50.1 (9.3)	–	37.3 (9.1)	–
Endo et al., 201236	50	31.5 (7.4)	37.2 (7.1)	8.6 (5.5)	46.3 (8.5)	18.5 (10.9)	30.9 (10)	45.7 (8.2)
Weighted Average (mean [95% CI])			34.3 [32.9; 35.7]	14.0 [11.0; 17.0]	47.2 [46.3; 48.0]	19.5 [16.9; 21.9]	33.9 [27.4; 40.5]	47.3[43.7; 50.9]

Table 3
Significance testing between sitting and standing radiographic measures.

Radiographic Outcomes	p-value
SVA	<0.0001
TK	0.368
LL	<0.0001
SS	<0.0001
PT	<0.0001
PI	0.9114

image using either stitched images or full-standing radiographs. In normal standing posture, TK and LL can be assessed. The improper distribution of this balance can be caused by pathological or age-related spinal deformities, leading to functional disability. The normal values of kyphosis or lordosis are variable across the literature [48–50]. Cervical lordosis (CL) can be 30–50°, TK is 20–50°, and LL is between 31 and 79° [51]. The pelvis and lower limbs are also important components for the proper alignment of the vertebrae. The literature indicates standing SS is about 40°, PI is about 52°, and PT is $< 20°$ [52]. Tables 1 and 2 display findings similar to these reported measures. The spine can compensate for sagittal imbalance with a lumbar lordotic state and increased pelvic tilt to maintain a proper center of gravity [53].

The purpose of this study was to find the differences between standing and sitting radiographic measures while creating a standard reference for all healthy subjects in the literature. The sitting spine has differences in various postural measures compared to standing radiographs. The normal sitting position induces thoracic and lumbar flexion, allowing for pelvic retroversion [38]. As expected, LL is decreased in the sitting position which may affect load sharing and stress distribution on posterior implants, such as pedicle screws [20]. Our findings suggest standing LL is reduced by nearly half. There is the forward displacement of the SVA in the sitting position, which could potentially lead to higher stress concentrations on anterior implants, such as interbody cages or anterior plates. The SS decreases from the standing to the sitting position, which indicates a more horizontal pelvis. PT was found to be increased in all patients in the sitting position compared to the standing position.

The awareness of these drastic changes in most radiographic measures is important in the pre-operative planning of surgical intervention, especially for a non-ambulatory population. To surgically manipulate the spine without these considerations could prevent the natural sitting position and induce undue stress on implants, leading to junctional failure and repeat procedures. Radiographic measures should be compared to the normal criteria established in research such as this systematic review. The major limitation of this analysis is due to the limited number of studies looking at pre-operative vs postoperative changes in sitting vs standing radiographic measures [34,54]. This does not allow us to draw direct conclusions on the impact of these specific changes in sitting and standing radiographic measures on outcomes in various spinal disorders. Another limitation of the manuscript is that we include a wide range of mean ages, 23.1–75.6 years old, in the weighted mean. We did demonstrate that several radiographic measures are significantly correlated with age, which represents a moderating factor in the data. Additionally, the literature has shown differences among upright versus erect sitting postures. When sitting in a natural position, a vague C shape is formed, which can significantly affect the values of various measures [18]. Two studies indicated the use of a natural sitting position [44,46], while the remaining indicated an erect sitting position [3,36–38,40,42,45,47]. This was not controlled for in our systematic review and should be a noted limitation.

Conducting a well-controlled and targeted study to increase our understanding of the consequences of radiographic measurements for spinal surgery is critical. To reduce heterogeneity, specific patient categories should be created based on age, spinal condition, and surgical aims. Radiographic measurement techniques with precise parameters and approved measurement instruments should be developed. To achieve consistency and accuracy, standardized patient positioning techniques should be implemented. Incorporating proven outcome measures, such as patient-reported outcomes and functional assessments, will provide a complete picture of the clinical impact. By applying these recommendations, future research will be able to give a thorough understanding of the association between radiographic measurements and surgical outcomes, thereby improving clinical decision-making and patient outcomes across a wide range of spinal disorders and demographics.

5. Conclusion

The spinopelvic relationship is complex. As demonstrated in this systematic review, there are major differences in the standards of reference for sitting and standing radiographs. Assessing radiographic measures in different postures could lead to a better understanding of sagittal balance and influence decision-making during surgery.

Disclosures

The authors have no conflicts of interest.

Conflict of interest

Nothing to disclose.

Data availability statement

All data supporting the findings of this study are available within the manuscript.

CRediT authorship contribution statement

Rajiv Dharnipragada: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nick Bostrom:** Writing – original draft, Methodology, Data curation. **Mario Bertogliat:** Writing – review & editing, Methodology, Investigation. **Lalitha S. Denduluri:** Writing – review & editing, Methodology, Investigation, Data curation. **Sanjay Dhawan:** Writing – review & editing, Writing – original draft, Validation, Supervision. **Bryan Ladd:** Writing – review & editing, Writing – original draft, Validation, Supervision. **Sarah Woodrow:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Ann M. Parr:** Writing – review & editing, Writing – original draft, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28545.

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