Comparison of Cobb angle measurements for scoliosis assessment using different imaging modalities: a systematic review

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• **Purpose:** To report accuracy, repeatability, and agreement of Cobb angle measurements on radiographs and/or stereo-radiographs (EOS) compared against one another or against other imaging modalities.

• **Methods:** This review follows Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines. A literature search was conducted on 21 July 2021 using Medline, Embase, and Cochrane. Two researchers independently performed title/abstract/full-text screening and data extraction. Studies were eligible if they reported Cobb angles, and/or their repeatability and agreement, measured on radiographs and/or EOS compared against one another or against other imaging modalities.

• **Results:** Of the 2993 records identified, 845 were duplicates and 2212 were excluded during title/abstract/full-text screening. Two more relevant studies were identified from references of eligible studies, leaving 14 studies for inclusion. Two studies compared Cobb angles from EOS vs CT, while 12 compared radiographs vs other imaging modalities: EOS, CT, MRI, digital fluoroscopy, or dual-energy x-ray absorptiometry. Angles from standing radiographs tended to be higher than those from supine MRI and CT, and angles from standing EOS tended to be higher than those from supine or prone CT. Correlations across modalities were strong ($R = 0.78–0.97$). Inter-observer agreement was excellent for all studies (ICC = 0.77–1.00), except one (ICC = 0.13 radiographs and ICC = 0.68 for MRI).

• **Conclusion:** Differences of up to 11° were found when comparing Cobb angles across combinations of imaging modalities and patient positions. It is not possible, however, to determine whether the differences observed are due to the change of modality, position, or both. Therefore, clinicians should be careful when utilizing the thresholds for standing radiographs across other modalities and positions for diagnosis and assessment of scoliosis.

**Keywords**
- scoliosis
- Cobb angle
- imaging modalities
- radiographs
- EOS
- agreement

**Introduction**

Scoliosis is a three-dimensional (3D) spinal deformity in the coronal, sagittal, and/or transverse planes (1). Nonetheless, in daily clinical practice, scoliosis is commonly assessed by measuring spinal curvature in the coronal plane only, by means of standing antero-posterior (AP) radiographs (2, 3, 4). The Cobb angle measured on two-dimensional (2D) AP radiographs in the standing position is used to quantify scoliosis in the coronal plane, usually with angles above 10° indicating mild scoliosis, and angles above 30° or 40° indicating severe scoliosis (4, 5, 6).

With technological advancements, stereo-radiography (EOS) is increasingly used for the diagnosis of scoliosis because it enables the assessment of spinal deformities in 3D in the standing position with minimal exposure to radiation (7, 8). The authors’ clinics, as most spine deformity centers worldwide, are equipped with low-dose EOS machines that expose patients to less radiation than conventional radiographs (9, 10), therefore having important safety implications for patients who require frequent monitoring (11). However, it is not clear whether Cobb angles measured using stereo-radiographs are equivalent to those measured on plain radiographs or other imaging modalities. Moreover, even though imaging...
modalities that assess spine deformity during standing are the reference standard, knowing the differences in Cobb angles between standing and supine positions is relevant when assessing curve flexibility, which can influence decision-making regarding treatment.

There is no systematic review to date that describes the imaging modalities available to diagnose scoliosis and that synthesizes their repeatability and agreement. Therefore, the purpose of this systematic review is to report on the accuracy, repeatability, and agreement of Cobb angles measured on radiographs and/or EOS compared against one another or against other imaging modalities. These findings could help ascertain thresholds for assessment of scoliosis to each imaging modality and patient position and hence enable clinicians to adjust their diagnostic criteria depending on the technology and procedures available at their centers.

Materials and methods

The protocol for this systematic review was submitted to PROSPERO prior to commencement (registration number CRD42021264063) and follows the guidelines established by the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) (12). The original PROSPERO registration stated that the purpose would be to report on the repeatability and accuracy of Cobb angles measured across different imaging modalities and/or different measurement techniques. Due to the large number of studies reporting on different measurement techniques, the purpose of this systematic review was altered compared to that submitted to PROSPERO, to only include studies reporting on plain radiographs and/or EOS compared against one another or against other imaging modalities.

Search strategy

The authors conducted a structured electronic literature search on 21 July 2021 using the Medline, Embase, and Cochrane Central Register of Controlled Trials databases, applying the keywords and medical subject heading (MeSH) terms presented in the Supplementary file (see section on supplementary materials given at the end of this article). After the removal of duplicate records, two researchers (SB, SRP) each screened the titles and abstracts to determine the suitability for the review against predefined eligibility criteria:

Inclusion criteria

• Clinical studies reporting Cobb angles, as well as the repeatability and agreement of Cobb angles, measured on radiographs and/or EOS compared against one another or against other imaging modalities, where the population is patients assessed for scoliosis.

Exclusion criteria

• Studies that did not report on live human participants (e.g. cadavers, phantoms, or animals).
• Studies that reported on computer simulations.
• Studies that compared radiographs or EOS against surface imaging modalities, such as Moire topography, photogrammetry, raster-stereography, and pictures of the spine using smartphones.
• Studies that did not report on the Cobb angle but instead measured other coronal angles to assess deformity, such as the spinous process angle or the transverse process angle.
• Studies that did not report on coronal Cobb angle but instead measured sagittal Cobb angle (lumbar lordosis or thoracic kyphosis).
• Case reports, reviews, editorials, expert opinions, or conference proceedings.
• Studies written in languages other than English, French, or Spanish to avoid translation errors.

Study selection

Full-text review of studies meeting the criteria in the initial screening was carried out by two researchers (SB, SRP), and any disagreement about the final eligibility of studies was resolved by review and consensus. Subject experts (HdA, MS, JCLH) were consulted to further establish relevant studies not captured by the database searches.

Data extraction and quality assessment

Data extraction was performed by two researchers (SB, SRP) independently, and their results were compared to ensure accuracy. Where there was disagreement in the documented value, the true value was ascertained by a simultaneous review of the data in question by both researchers. The following data were extracted from the included studies: author(s), journal, year of publication, ethical approval, and conflicts of interest. Cohort characteristics were retrieved, including the type of cohort (e.g. scoliotic and volunteers), number of subjects, sex, age, and body mass index (BMI). Furthermore, the following were also retrieved: imaging modalities used, time between imaging modalities, subject position, number of observers, number of measurements per observer, type of curves measured (e.g. main and secondary), Cobb angle for each combination of modality and position, difference in Cobb angle between these combinations, Cobb angle thresholds, inter-
Results

The systematic search returned 2993 records, of which 845 were duplicates, leaving 2148 records for screening. After full-text review because they did not report coronal Cobb angles, two studies (35, 46) were excluded because they were not comparative; one study (36) was excluded because it reported on cadavers, and one study (38) was excluded because it reported on cadavers and only study (39) was included.

Cobb angles and Cobb angles for subgroups were reported by four studies (15, 17, 18, 19). Intra-observer reliability was presented for more than one observer, and the additional data are presented in the Supplementary file. Furthermore, when intra-observer reliability was presented for more than one observer, only the data for the first observer were presented in the Supplementary file.

Table 1: Information of the comparative studies included in the systematic review.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study design</th>
<th>Ethical approval</th>
<th>COI</th>
<th>Funding</th>
<th>Country</th>
<th>Patient condition</th>
<th>Imaging modality 1</th>
<th>Imaging modality 2</th>
<th>Time between imaging modalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Aubaidi et al. (47)</td>
<td>R</td>
<td>Yes</td>
<td>None</td>
<td>NA</td>
<td>NA</td>
<td>Scoliosis</td>
<td>EOS</td>
<td>CT</td>
<td>&lt;6 months</td>
</tr>
<tr>
<td>Brink et al. (49)</td>
<td>R</td>
<td>NR</td>
<td>None</td>
<td>Yes</td>
<td>Netherlands</td>
<td>AIS</td>
<td>X-ray</td>
<td>Prone</td>
<td>61 ± 30 days</td>
</tr>
<tr>
<td>Diefenbach et al. (46)</td>
<td>P</td>
<td>Yes</td>
<td>None</td>
<td>USA</td>
<td>AIS</td>
<td>AIS</td>
<td>Standing</td>
<td>CT</td>
<td>81 ± 31 days</td>
</tr>
<tr>
<td>Geijer et al. (51)</td>
<td>NA</td>
<td>Yes</td>
<td>NA</td>
<td>NA</td>
<td>Sweden</td>
<td>AIS</td>
<td>Standing</td>
<td>CT</td>
<td>3 ± 17 days</td>
</tr>
<tr>
<td>Hinsic et al. (7)</td>
<td>P</td>
<td>Yes</td>
<td>None</td>
<td>France</td>
<td>AIS</td>
<td>AIS</td>
<td>Standing</td>
<td>CT (MRI)</td>
<td>&lt;1 week</td>
</tr>
<tr>
<td>Lechner et al. (41)</td>
<td>R</td>
<td>NR</td>
<td>None</td>
<td>Yes</td>
<td>Austria</td>
<td>Scoliosis (IP or NP)</td>
<td>Standing</td>
<td>EOS (3D patient plane)</td>
<td>NA</td>
</tr>
<tr>
<td>Lee et al. (45)</td>
<td>R</td>
<td>Yes</td>
<td>None</td>
<td>USA</td>
<td>AIS</td>
<td>AIS</td>
<td>Supine</td>
<td>Supine</td>
<td>&lt;6 months (1 ± 1)</td>
</tr>
<tr>
<td>Schill et al. (39)</td>
<td>R</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>USA</td>
<td>With and without scoliosis</td>
<td>X-ray</td>
<td>MRI</td>
<td>&lt;6 months (3.2 ± 2.0)</td>
</tr>
<tr>
<td>Shet et al. (44)</td>
<td>R</td>
<td>Yes</td>
<td>None</td>
<td>China</td>
<td>AIS</td>
<td>AIS</td>
<td>Standing</td>
<td>MRI</td>
<td>&lt;6 months (3.2 ± 2.0)</td>
</tr>
<tr>
<td>Tauchi et al. (43)</td>
<td>R</td>
<td>Yes</td>
<td>None</td>
<td>None</td>
<td>NA</td>
<td>Congenital scoliosis</td>
<td>Standing</td>
<td>CT (3D)</td>
<td>Supine</td>
</tr>
<tr>
<td>Varshak &amp; Tropp (42)</td>
<td>RO</td>
<td>Yes</td>
<td>None</td>
<td>Sweden</td>
<td>AIS</td>
<td>Sas (requiring surgery)</td>
<td>Standing</td>
<td>CT (2D. scout view)</td>
<td>Supine</td>
</tr>
<tr>
<td>Wessberg et al. (48)</td>
<td>P</td>
<td>NA</td>
<td>Yes</td>
<td>Sweden</td>
<td>AIS</td>
<td>Sas (brace treatment)</td>
<td>Standing</td>
<td>CT (MRI)</td>
<td>&lt;1 h</td>
</tr>
<tr>
<td>Yazici et al. (50)</td>
<td>A</td>
<td>NA</td>
<td>NA</td>
<td>Turkey</td>
<td>AIS</td>
<td>AIS (requiring surgery)</td>
<td>Standing</td>
<td>CT (2D. scout view)</td>
<td>NA</td>
</tr>
<tr>
<td>Yeung et al. (40)</td>
<td>P</td>
<td>Yes</td>
<td>None</td>
<td>None</td>
<td>Hong Kong</td>
<td>AIS (requiring surgery)</td>
<td>EOS (3D patient plane)</td>
<td>MRI</td>
<td>&lt;2 weeks</td>
</tr>
</tbody>
</table>

A, ambispective; AIS, adolescent idiopathic scoliosis; C, cassette; COI, conflicts of interest; D, digital; DEXA, dual-energy x-ray absorptiometry; EOS, stereo-radiography; IP, idiopathic; NA, not available; NP, neuropathic; NR, not required; P, prospective; PF, plain film; R, retrospective; RO, retrospective observational; SLD, supine lateral bending.

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Figure 1
Flowchart describing inclusion and exclusion of articles for the systematic review.

Study characteristics
The 14 included studies reported on a combined total of 646 individuals (Table 2), of which 11 studies (7, 39, 40, 41, 42, 44, 46, 47, 48, 49, 50) reported mean patient age, which ranged from 13.6 to 18.4 years in 10 studies but was 69.2 years in 1 study (39). Twelve studies (7, 39, 40, 42, 43, 44, 45, 46, 47, 48, 49, 50) reported on sex distribution, with the percentage of males ranging between 0 and 55%. Only two of the studies (40, 45) reported on BMI, with mean values of 19.5 and 23.0 kg/m². Nine studies (7, 40, 42, 44, 45, 46, 48, 49, 50) reported on individuals with adolescent idiopathic scoliosis (AIS), one (41) reported on individuals with idiopathic or neuropaortic scoliosis, one (43) reported on individuals with congenital scoliosis, one (47) reported on individuals with scoliosis, one (39) reported on individuals with and without scoliosis, and lastly one (51) did not specify patient conditions.

Of the 14 studies, only three compared Cobb angles in the same position using different imaging modalities: standing radiographs vs standing dynamic MRI (46), standing radiographs vs standing digital fluoroscopy (51), and supine radiographs vs supine CT (41). The remaining 10 studies compared Cobb angles across imaging modalities in different positions: one (7) study compared supine lateral bending radiographs vs standing lateral bending EOS, three (42, 43, 50) studies compared standing radiographs vs supine CT, three (44, 45, 48) studies compared standing radiographs vs supine MRI, two (40, 47) studies compared standing EOS vs supine or prone CT, (7) one (39) study compared standing radiographs vs supine dual-energy x-ray absorptiometry (DEXA), and, finally, one (49) study compared standing radiographs vs supine MRI vs prone CT.

Cobb angles
Of the 14 studies, 11 (7, 39, 40, 41, 42, 44, 45, 47, 48, 50, 51) compared Cobb angles across two imaging modalities (Table 3, Figs. 3, 4 and 5), one (49) compared Cobb angles across three imaging modalities, and six (39, 42, 45, 48, 50, 51) reported the mean difference in Cobb angle between two imaging modalities. Of the studies that compared Cobb angles in the same position using different imaging modalities: one study (51) found similar

Table 2 Characteristics of the individuals participating in the studies included in the systematic review.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Cohort size</th>
<th>Mean ± S.D.</th>
<th>Range</th>
<th>Males, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Aubaidi et al. (47)</td>
<td>7</td>
<td>15.4 ± 4.1°</td>
<td>10.0–18.0</td>
<td>3 (43)</td>
</tr>
<tr>
<td>Brink et al. (49)</td>
<td>62</td>
<td>15.6 ± 2.5</td>
<td>10.0–23.0</td>
<td>56 (90)</td>
</tr>
<tr>
<td>Diefenbach et al. (46)</td>
<td>25</td>
<td>14.6 ± 2.6</td>
<td>12.0–18.0</td>
<td>9 (36)</td>
</tr>
<tr>
<td>Geijer et al. (51)</td>
<td>10</td>
<td>15.6 ± 1.9</td>
<td>12.0–18.0</td>
<td>10 (20)</td>
</tr>
<tr>
<td>Hirsch et al. (7)</td>
<td>50</td>
<td>15.6 ± 1.9</td>
<td>12.0–18.0</td>
<td>10 (20)</td>
</tr>
<tr>
<td>Lechner et al. (41)</td>
<td>55</td>
<td>14.0 ± 2.0</td>
<td>10.0–18.0</td>
<td>30 (43)</td>
</tr>
<tr>
<td>Lee et al. (45)</td>
<td>70</td>
<td>14.4 ± 1.8</td>
<td>10.5–17.1</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Schell et al. (39)</td>
<td>51</td>
<td>69.2 ± 10.3</td>
<td>4 (8)</td>
<td></td>
</tr>
<tr>
<td>Shi et al. (44)</td>
<td>80</td>
<td>14.4 ± 1.8</td>
<td>10.5–17.1</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Tauch et al. (43)</td>
<td>20</td>
<td>11 (55)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vavruh &amp; Tropp (42)</td>
<td>128</td>
<td>15.5</td>
<td>11.0–26.0</td>
<td>31 (24)</td>
</tr>
<tr>
<td>Wessberg et al. (48)</td>
<td>30</td>
<td>13.6</td>
<td>12.0–16.0</td>
<td>12 (1)</td>
</tr>
<tr>
<td>Yazici et al. (50)</td>
<td>25</td>
<td>14.2</td>
<td>10.0–16.0</td>
<td>8 (32)</td>
</tr>
<tr>
<td>Yeung et al. (40)</td>
<td>33</td>
<td>18.4 ± 4.2</td>
<td>13.0–31.0</td>
<td>7 (21)</td>
</tr>
</tbody>
</table>

*Values in parentheses have been calculated by the authors of the present study.

Figure 2
Methodological quality of the eligible studies was assessed independently by two researchers according to the QUADAS evidence-based tool for diagnostic accuracy studies.
Table 3  Cobb angle measurements from the studies included in the systematic review.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Curve measured</th>
<th>Cobb angle: modality 1</th>
<th>Cobb angle: modality 2</th>
<th>Difference</th>
<th>Linear regression analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± s.d.</td>
<td>Range</td>
<td>Mean ± s.d.</td>
<td>r-value</td>
</tr>
<tr>
<td>Al-Aubaidi et al.</td>
<td>Main</td>
<td>32.0 ± 15.8</td>
<td>14–78</td>
<td>27.0 ± 12.3</td>
<td>0.56</td>
</tr>
<tr>
<td>Brinck et al.</td>
<td>Main</td>
<td>68.2 ± 15.4</td>
<td>62–13.5</td>
<td>59.3 ± 14.8</td>
<td>0.77</td>
</tr>
<tr>
<td>Diefenbach et al.</td>
<td>Main</td>
<td>68.2 ± 15.4</td>
<td>53.9 ± 14.8</td>
<td>61.4 ± 15.4</td>
<td>0.64</td>
</tr>
<tr>
<td>Geijer et al.</td>
<td>Pre-selected levels</td>
<td>14.8 ± 0.9</td>
<td>14.4 ± 0.9</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Hirsch et al.</td>
<td>Main</td>
<td>23.5 ± 15.5</td>
<td>22.7 ± 17.0</td>
<td>&gt;0.05</td>
<td></td>
</tr>
<tr>
<td>Lechner et al.</td>
<td>Main</td>
<td>63.6 ± 32.0</td>
<td>72.8 ± 28.5</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Lee et al.</td>
<td>All curves</td>
<td>58.0 ± 14.0</td>
<td>48.0 ± 14.0</td>
<td>9.2</td>
<td></td>
</tr>
<tr>
<td>Schell et al.</td>
<td>LI-L4</td>
<td>10.9 ± 9.5</td>
<td>8.1 ± 7.3</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>Shi et al.</td>
<td>Structural and non-structural</td>
<td>29.4 ± 13.7</td>
<td>22.4 ± 14.3</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>Vavra &amp; Tropp</td>
<td>Main</td>
<td>59.2 ± 11.5</td>
<td>48.1 ± 11.7</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Wessberg et al.</td>
<td>All curves</td>
<td>30.8 ± 5.5</td>
<td>23.5 ± 3.5</td>
<td>11.1 ± 5.2</td>
<td></td>
</tr>
<tr>
<td>Yazici et al.</td>
<td>Structural</td>
<td>55.7 ± 16.8</td>
<td>39.4 ± 10.8</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Yeung et al.</td>
<td>Main</td>
<td>62.9 ± 9.3</td>
<td>47.3 ± 10.0</td>
<td>0.86</td>
<td></td>
</tr>
</tbody>
</table>

Notes on Cobb angle measurements: Lechner et al. selected end vertebrae by the senior author on x-ray and CT; Lee et al. selected the same end vertebrae for x-ray and MRI; Shi et al. selected end vertebrae on x-ray for MRI. Wessberg et al. selected end vertebrae on x-ray for MRI.

1Values in parentheses have been calculated by the authors of the present study; “Scoliotic curves were on average 29.8% (0–55%)” greater on x-ray compared to CT.

Table 4  Correlations between modalities and repeatability of Cobb angles.

<table>
<thead>
<tr>
<th>Modality</th>
<th>Intraclass Correlation Coefficient (ICC)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOS</td>
<td>ICC = 0.99</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CT</td>
<td>ICC = 0.88</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MRI</td>
<td>ICC = 0.96</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Of the 14 studies, eight (39, 40, 41, 43, 44, 45, 46) calculated correlations between modalities, as well as intra- and interobserver agreement for standing radiographs (ICC = 0.99) and for standing or supine MRI (ICC = 0.96). Five studies reported strong agreement between modalities as well as intra- and interobserver agreement (Table 4). All eight studies reported strong agreement for CT (ICC > 0.85) and for standing or supine MRI (ICC > 0.90). One study (45) reported excellent and good agreement for EOS (ICC > 0.90) and for standing or supine MRI (ICC > 0.90). All studies reported strong agreement for EOS (ICC > 0.90) and for standing or supine MRI (ICC > 0.90).
Thresholds used to define scoliosis

Of the 14 studies, only three (39, 44, 48) reported on Cobb angle thresholds used for defining scoliosis. Schell et al. (39) defined scoliosis as a Cobb angle ≥10° when comparing radiographs vs DEXA, while Wessberg et al. (48) defined scoliosis as >20° when comparing radiographs vs MRI. Furthermore, Shi et al. (44) defined moderate scoliosis as >20° and severe scoliosis as >40° when comparing radiographs vs MRI.

Discussion

This systematic review identified 14 relevant studies that compared Cobb angles measured on radiographs and/or EOS, against one another or against other imaging modalities. Only two studies directly compared Cobb angle measurements in the same position using different imaging modalities, of which one found similar angles using standing radiographs and standing digital fluoroscopy (51) and the other found angles from supine radiographs to be 9° lower than those from supine CT (41). For studies comparing Cobb angles across different imaging modalities and patient positions, four studies found them to be 7.0–11.5° higher on standing radiographs compared to supine MRI (44, 45, 48, 49), three studies found them to be 11.1–16.3° higher on standing radiographs compared to supine/prone CT (42, 49, 50), and two studies found them to be 5.0–15.6° higher on standing EOS compared to supine/prone CT (40, 47). It is not possible, however, to determine whether the differences observed are due to the change of modality, or position, or both. Therefore, clinicians should be careful when utilizing the thresholds for standing radiographs across other modalities and positions for diagnosis and assessment of scoliosis.

Surprisingly, only one study compared Cobb angles measured on radiographs vs EOS, albeit in different positions, and found similar angles across modalities (respectively, 23.5 ± 15.5 vs 22.7 ± 17.0, P > 0.05) (7); radiographs were acquired in supine lateral bending, while EOS images were acquired in standing lateral bending. It is worth noting that a previous study (52) that compared Cobb angles from radiographs in standing vs
supine positions found a statistically significant difference between measurements (respectively, $26\pm12^\circ$ vs $21\pm12^\circ$, $P < 0.01$), as gravity exacerbated the deformity. In contrast, another study (53) that compared segmental Cobb angles from MRI in standing vs supine positions found that the L5-S1 Cobb angle significantly decreased in standing ($P < 0.05$), while there were no significant differences at L1–L2, L2–L3, and L3–L4 ($P > 0.05$).

With technological advancements, EOS and other EOS machines are most commonly used in spine deformity centers worldwide for the diagnosis of scoliosis, because they enable the assessment of spinal deformities in 3D in the straight standing position with minimal exposure to radiation while also measuring spino-pelvic parameters. However, since none of the studies in this systematic review compared Cobb angles in a straight standing position, from radiographs vs EOS, it is not possible to determine whether angles from these two imaging modalities are equivalent or not.

Differences in Cobb angles across modalities varied per study, though as expected, angles from standing radiographs were higher than those from supine MRI and CT, and similarly, angles from standing EOS tended to be higher than those from supine or prone CT. However, there was one exception to this, Wessberg et al. (48) found no differences in Cobb angle when comparing standing radiographs and supine loaded MRI. Interestingly, when comparing Cobb angles across different imaging modalities in the same position, Lechner et al. found that Cobb angles on supine radiographs were on average $9.2^\circ$ smaller than on supine CT and concluded that this was because CT was performed in 3D while radiographs in 2D. Geijer et al. (51) found no differences in Cobb angle between standing radiographs vs standing digital fluoroscopy and concluded that digital fluoroscopy had the added advantage of lower radiation.

Studies that measured the correlation between modalities always found them to be strong ($R=0.78–0.97$), though it is worth noting that a strong correlation does not necessarily imply that measurements are equal. Furthermore, inter-observer agreement was excellent for all studies (ICC=0.77–1.00), with the exception of Shi et al. (44), who reported coefficients of 0.13 and 0.47 for patients with mild scoliosis (Cobb angle: $<20^\circ$) on radiographs and MRI, respectively. This implies that inter-observer agreement is low in patients with little-to-no scoliosis, where selecting end vertebrae is more challenging.

Interestingly, only three of the 14 included studies reported on Cobb angle thresholds used for defining scoliosis, with one study defining scoliosis as a Cobb angle $\geq 10^\circ$, another as a Cobb angle $>20^\circ$, and the last one defining moderate scoliosis as a Cobb angle $>20^\circ$ and severe scoliosis as a Cobb angle $>40^\circ$. It is therefore possible that the thresholds for assessment of scoliosis specific to each imaging modality may need to be adjusted to avoid misdiagnosis due to inappropriate assumptions and definitions.

This systematic review has a number of limitations. First, there is a low number of published studies comparing Cobb angle measurements across imaging modalities; only seven studies reported mean Cobb angle measurement differences across modalities, and only two of these reported mean and s.d. values; therefore a meta-analysis could not be performed. Second, there was some heterogeneity across the included studies in terms of the patient condition, with some studies not specifying the type of scoliosis, other studies including patients with and without scoliosis, and other studies not at all specifying the patient condition. Third, one of the 14 studies included patients without scoliosis, and the repeatability of Cobb angle measurements in non-scoliotic patients is difficult, since there is no deformity, and thus no obvious upper and lower vertebrae. Fourth, for certain studies, the reader was not blinded when measuring the Cobb angle, and the end vertebrae were selected beforehand.

![Figure 5](https://www.efortopenreviews.org/)

**Figure 5**
Cobb angle measurements for studies comparing other imaging modalities, presented as mean ± S.D.
Conclusions

This systematic review identified 14 relevant studies that compared Cobb angles measured on radiographs and/or EOS against one another or against other imaging modalities and found differences of up to 11° when comparing Cobb angles across combinations of imaging modalities and patient positions. It is not possible, however, to determine whether the differences observed are due to the change of modality, or position, or both. Therefore, clinicians should be careful when utilizing the thresholds for standing radiographs across other modalities and positions for diagnosis and assessment of scoliosis.

Supplementary materials

This is linked to the online version of the paper at https://doi.org/10.1530/EOR-23-0032.

ICMJE conflict of interest statement

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