Spinal Flexibility Assessment on the Patients with Adolescent Idiopathic Scoliosis (AIS): A Literature Review

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Abstract

Study Design: Literature review

Objective: To review the contemporary methods for spinal flexibility assessment on the patients with adolescent idiopathic scoliosis (AIS).

Summary of Background Data: Spinal flexibility is one of the essential parameters for clinical decisions on the patients with AIS. Various methods of spinal flexibility assessment are proposed, but which method(s) could better reveal spinal flexibility or predict treatment effect is unclear.

Methods: The databases of AbleData, IBSS, Academic Search Premier, MEDLINE/PubMed, CINAHL, Recal Legacy, REHABDATA, Embase and Web of Science were searched. The study inclusive criteria were: (1) prospective cohort study; (2) investigated spinal flexibility on AIS patients; (3) published in English 1996-2016.

Results: Totally fifteen articles were included and eleven methods of spinal flexibility assessment were introduced in this review. Traction methods revealed higher spinal flexibility on the patients with severe curves (>65°) but lower spinal flexibility on the patients with moderate curves (40-65°), comparing with lateral bending methods. Among lateral bending methods, fulcrum bending flexibility is higher on thoracic (T) curves whereas supine with lateral bending flexibility is higher on thoracolumbar or lumbar (TL/L) curves. For predicting postoperative correction, fulcrum bending flexibility showed higher correlation with postoperative correction on moderate curves and traction flexibility showed higher correlation on severe curves, comparing with supine with lateral bending method.

Conclusions: Curve magnitude and location are two important parameters in selecting appropriate method for spinal flexibility assessment and treatment effect prediction. The traction
method should be considered for the patients with severe curves, while the lateral bending method is suggested for the patients with moderate curves. The fulcrum bending method is recommended to assess T curve flexibility whereas the supine with lateral bending method is for the assessment of TL/L curve flexibility. A comprehensive guideline for selecting spinal flexibility assessment method(s) should be established via future studies.

**Key Words:** spinal flexibility; scoliosis; AIS; postoperative correction; supine bending; traction; fulcrum bending; suspension; push prone

**Level of Evidence:** 4
Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional (3D) deformity of the spine and rib cage, which occurs predominantly in prepubertal girls. It is generally diagnosed with posteroanterior and lateral radiographies using the Cobb angle. The prevalence of scoliosis ranges 2–3%. Currently, the standard care for AIS includes: observation, for the patients with small curves or skeletal maturity; brace treatment, for those with moderate curves and skeletal immaturity; and operation, for those with severe curves.

Spinal flexibility describes the mathematical ratio between the displacement of spine and the force vector applied to generate this motion. However, direct and quantitative assessment of the displacement and force on the spine may not be feasible. The current clinical practice is to compare the Cobb angle in a corrected posture or under reduction force to the Cobb angle in standing posture, and define the correctability of the Cobb angle as spinal flexibility. Supine with lateral bending method has been used as a gold standard to assess spinal flexibility and predict postoperative correction, but the prediction accuracy of this method has been questioned with the advancements of surgical instruments. Various methods (such as fulcrum bending etc.) emerge in recent years. Among these methods, which method(s) could better reveal spinal flexibility or better predict treatment effect has not been thoroughly studied. This study aims to review the contemporary methods for spinal flexibility assessment and compare these methods on revealing spinal flexibility and predicting treatment effect.
Materials and Methods

Searching Strategy

The databases of AbleData, IBSS, Academic Search Premier, MEDLINE/PubMed, CINAHL, Recal Legacy, REHABDATA, Embase and Web of Science were searched. Various combinations of the key words “scoliosis”, “flexibility”, “reducibility” and “elasticity” were used to screen for potentially relevant studies. The study inclusive criteria are: 1) prospective cohort study; 2) investigated the spinal flexibility on the patients with AIS; 3) published in English from 1996 to 2016.

Quality Assessment and Data Extraction

Quality Assessment

The Methodological Index for Non-Randomized Studies (MINORS) was used to assess the quality of included studies. It is a valid instrument consisting of 12 items designed to assess the methodological quality of non-randomized surgical studies. All items have a “not reported”, “reported but inadequate” or “reported and adequate” answer option, with the score of 0 point, 1 point and 2 points respectively. In addition, the 2011 Oxford Centre for Evidence-Based Medicine Levels of Evidence was used to determine the level of evidence of each included study.

Data Extraction and analysis

For each study, a data extraction form was used to make a summary of the study characteristics and study results. The following items were extracted: author/year, study design, study sample, operation type, flexibility assessment methods, spinal flexibility and postoperative correction (if applicable).
Results

Study Selection

A total of 82 articles and abstracts were found in the literature search. After eligibility screening, 15 articles were included in this literature review (Figure 1).

Methodological Quality

The results of the methodological assessment are presented in Table 1. All studies were prospective cohort studies with clearly stated study aims. To fulfill the study aims, the endpoints/follow-up period was appropriate and no loss of follow-up was reported. However, the most prevalent shortcomings of the trials were lack of endpoints evaluation and prospective sample size calculation. In addition, five studies did not report subject recruitment method and three studies reported prospective recruitment of subjects without specifying whether the subjects were consecutive or not. The results of level of evidence assessment are presented in Table 2. Most studies are at evidence level 3.

Study Characteristics

Table 2 presents a short description of the study design, level of evidence, study sample, operation type and outcome measure for each article included in the literature review.

A total of 11 methods (5 categories) for spinal flexibility assessment were introduced: (1) supine method; (2) lateral bending method (supine/standing with lateral bending, fulcrum bending); (3) manual correction method (supine/prone with manual correction); (4) traction method (standing/supine traction, supine traction under general anesthesia (UGA)); and (5) traction and manual correction method (with/without anesthesia). Five studies investigated different methods on the ability of revealing spinal flexibility. Ten studies investigated the predictability of spinal
flexibility to postoperative correction. All studies used the traditional X-ray system for spinal flexibility assessment except for one study which applied EOS system. Ten studies took posteroanterior standing radiograph and one study took anteroposterior standing radiograph, while the other three studies did not mention their assessment techniques. The sample size ranged from 5 to 127 in different studies. Eight studies grouped patients/curves according to the curve magnitude and location. The other studies either grouped patients according to surgical instrumentations or no grouping at all. Most subgroups of lumbar/thoracolumbar curves were less than 5 patients, indicating an overall low power. Five studies did not specify the initial Cobb angle of their studied subjects.

**Analysis**

**Assessment methods**

1. **Supine method**

   One study reported approximately 25% spinal flexibility in supine position.

2. **Lateral bending method**

   Nine studies investigated supine or standing with lateral bending method. Two studies reported higher flexibility of moderate curves than severe curves. Five studies reported higher flexibility of TL/L curves than T curves. Eight studies assessed the fulcrum bending flexibility and reported that the flexibility of T and TL/L were 45-74% and 53-83% respectively.

3. **Manual correction method**
Three studies\textsuperscript{11-13} investigated manual correction methods, which can be performed in supine or prone position. Two studies\textsuperscript{12,13} investigated prone with manual correction method, among which one grouped curves according to magnitude (<60° or ≥60°) and location (T and TL/L)\textsuperscript{12}, the other one was according to the curve location only (T and TL/L)\textsuperscript{13}. Moderate curve was superior to severe curves in revealing spinal flexibility, while no superiority was reported between T curve flexibility and TL/L curve flexibility (approximately 30-40% for T curves and 30-50% for L curves)\textsuperscript{12}. One study\textsuperscript{11} assessed the supine with manual correction method and reported no significant difference between T curve flexibility and TL/L curve flexibility.

4. Traction Method

Three studies\textsuperscript{5,18,19} investigated standing with traction (suspension) method. Among which one study grouped curves according to curve location\textsuperscript{18}. The flexibility of T curve and TL/L curve were approximately 40\% and 45\% respectively. The other two studies\textsuperscript{5,19} reported the overall reduction as 12-26° without grouping subjects in suspension method. It was noticed that Hirsch et al. firstly attempted to use EOS system in the spinal flexibility assessment\textsuperscript{18}. Two studies\textsuperscript{13,20} reported the supine with traction method and three studies\textsuperscript{9,12,13} investigated supine with traction method performed UGA, which proved the higher flexibility of supine traction UGA than without anesthesia (50-80\% vs 28-56\%)\textsuperscript{13}.

5. Traction and manual correction method

Two studies\textsuperscript{8,13} investigated supine traction and manual correction method. Main T and TL/L curves showed about 55\%, 65\% flexibility respectively. Two studies\textsuperscript{11,16} investigated supine traction and manual correction method performed UGA, and reported the spinal flexibility as approximately 55\% with T curve and L curve being corrected to about 40° and 27° respectively.
Discussion

This study reviewed contemporary methods for spinal flexibility assessment on the patients with AIS. A total of 15 studies (581 participants) were reviewed. Most of these studies are at evidence level 3 with a high methodological quality. Totally 11 assessment methods (5 categories) have been introduced: (1) supine method; (2) lateral bending method (supine/standing with lateral bending, fulcrum bending); (3) manual correction method (supine/prone with manual correction); (4) traction method (standing/supine traction, supine traction under general anesthesia (UGA)); (5) traction and manual correction method (with/without anesthesia). The comparison among different methods are shown in Table 3.

Spinal Flexibility Assessment

Supine with lateral bending method

Supine with lateral bending method is commonly used for flexibility assessment clinically. Supine position reduces axial loading, lateral bending generates lateral correction force, and exam bed exerts abdominal directed force to the spine, the combination effect of the three-dimensional force may result in deformity correction. Severe curves were reported to be less flexible than moderate curves in supine with lateral bending\textsuperscript{12,13}, which might be due to more severe deformity of vertebral tilting and distortion in the larger curves that construct a more rigid structure of the spine. In addition, T curves were reported less flexible than TL/L curves in this method\textsuperscript{7,8,12-14}, which could be explained by the relatively rigid structure of the rib cage in the thoracic region.

The generally accepted standard (supine with lateral bending) has been questioned in recent years because of the low reproducibility and decreased accuracy of postoperative
prediction. Therefore, various new methods have been proposed and investigated over the past few years.

1. Fulcrum bending method vs supine with lateral bending method

Fulcrum bending method could reveal higher spinal flexibility in both moderate and severe curves than supine with lateral bending method.\textsuperscript{13,21,22} It gave higher flexibility in T curves but similar flexibility in TL/L curves comparing with supine with lateral bending method.\textsuperscript{7} This may be owing to the force generated from the fulcrum bending (at fulcrum point) opposing the patient’s body weight being higher than the force generated by the muscles during active lateral bending.

2. Supine method vs supine with lateral bending method

The supine and supine with lateral bending flexibility were reported as approximately 25\%\textsuperscript{7} and more than 40\%\textsuperscript{7,8,11-14,23} respectively. It is understandable that extra self-bending force may create correction and increase the flexibility in supine with lateral bending method.

3. Manual correction method vs supine with lateral bending method

Prone with manual correction may reveal lower flexibility than supine with lateral bending and less accuracy to predict the postoperative correction.\textsuperscript{24,25} However, this method is still of high clinical value because it could better predict the translational correction and rotation of the last instrumented vertebra (LIV) than supine with lateral bending.\textsuperscript{25} Assess spinal balance via demonstrating the primary curve correction effect on upper and lower curves,\textsuperscript{7} and expose patients to less radiation via showing structural and compensatory curve correction on the same radiograph.
Supine with manual correction demonstrated similar flexibility but higher reproducibility comparing with supine with lateral bending method\textsuperscript{11}. It might because that the force applied by examiners could be better controlled and less affected by the patient’s effort or curve pattern.

4. Traction method vs supine with lateral bending method

Traction method can be performed in standing/supine/prone position, with/without anesthesia. Standing with traction (suspension) showed lower flexibility than supine with lateral bending for curves over 45°\textsuperscript{5}. Supine traction also showed lower flexibility than supine with lateral bending for curves less than 50°, whereas higher flexibility for curves over 60°\textsuperscript{26}. These findings validated that higher correction could be achieved with axial loading for severe curves and with transverse loading for moderate curves\textsuperscript{27,28}. When supine traction was performed UGA, the flexibility increased to be higher than that of supine with lateral bending, regardless of curvemagnitude\textsuperscript{9}. This indicated that patient’s muscle contraction would strongly affect curve correction during the flexibility assessment.

5. Traction and manual correction method vs supine with lateral bending method

Traction and manual correction can be performed with or without anesthesia. Supine traction and manual correction without anesthesia revealed higher flexibility on main T curves, equivalent flexibility on TL/L curves comparing with supine with lateral bending\textsuperscript{8}. Supine traction and manual correction UGA showed greater flexibility than supine with lateral bending\textsuperscript{11}, also higher flexibility than fulcrum bending in severe curves\textsuperscript{16}. The possible explanation is that anesthesia reduces muscle spasm which greatly limits the correctability of scoliotic curve.

**Postoperative Prediction**

Supine with lateral bending method
Takahashi et al. reported that the correlation of the Cobb angle in supine with lateral bending and postoperative radiographs are 0.81 and 0.41 in T and L curves respectively. King et al. and Lenke et al. also reported good predictability of supine with lateral bending method to postoperative correction, but the specific correlation was not provided. Even though supine with lateral bending was widely used to predict the correction of traditional instruments such as Harrington instrumentation, its predictability began to be questioned with the improved postoperative correction by modern instruments. Aronsson et al. demonstrated the inaccuracy of supine with lateral bending method as side bending (22° correction); Harrington instrumentation (23° correction); Wisconsin wires (29° correction) and Texas Scottish Rite Hospital instrumentation (36° correction). Its inability to predict the correction of pedicle screws and Cotrel-Dubousset system was reported as well. For predicting postoperative correction accurately and avoiding unnecessary fusion, new methods emerged and was investigated in recent years.

1. Fulcrum bending method vs supine with lateral bending method

Fulcrum bending is one of the commonly used lateral bending methods. The Cobb angle in fulcrum bending radiograph and postoperative radiograph were almost identical, while in supine with lateral bending radiograph and postoperative radiograph were different. To assess flexibility for T curves, the fulcrum bending demonstrated higher correction than that of supine with lateral bending. For upper T and TL/L curves, the correction of supine with lateral bending, fulcrum bending and postoperative correction was not significantly different. For moderate curves, fulcrum bending gave higher correction than that of supine with lateral bending and supine traction UGA and better prediction of postoperative correction. For severe curves, the
angle in supine traction UGA radiograph is closer to postoperative angle than that of fulcrum bending and supine with lateral bending radiographs 13.

2. Supine vs supine with lateral bending method

Supine position can reduce the axial loading on the spine due to gravity for evaluating the innate spinal flexibility. However, the supine flexibility (approximately 25% 7) was far less than the aim of postoperative correction. No study was found to compare supine method with supine with lateral bending method, or to adopt supine method to predict postoperative correction.

3. Manual correction method vs supine with lateral bending method

Supine with manual correction method was reported to show similar correction with supine with lateral bending but both corrections were less than postoperative correction 11. Even though the Cobb angle on prone with manual correction radiograph is larger than that on postoperative radiograph 7,25, the corrected Cobb angle was reported of no difference in another study 24. Thus, the different measurement parameters and surgical instrumentations in different studies made it difficult to draw a solid conclusion.

4. Traction method vs supine with lateral bending method

Standing with traction (suspension) is a new method for flexibility assessment. The ability of the suspension method to predict postoperative correction is unclear and deserves further investigation, considering the possibility of applying quantitative force and applicability to EOS. The supine traction and supine with lateral bending were reported to have equivalent ability to predict the postoperative correction 29. In comparison, supine traction method is advantageous in imaging the entire spine to evaluate the spinal balance 13,35, supine with lateral bending method is
advantageous in evaluating the mobility of each disc space in the L region. The supine traction UGA could better predict postoperative correction than supine with lateral bending, which may be owing to the increased correction achieved by anesthesia.

5. Traction and manual correction method vs supine with lateral bending method

Traction and manual correction flexibility was slightly lower than that of the postoperative correction, but not statistically significant. Comparing to supine with lateral bending, standing with traction (suspension) and fulcrum bending, traction and manual correction showed the highest predictability to postoperative correction, which might be due to higher correction to be achieved via dual effect of lateral and axial correction force to the scoliotic spine. When the traction and manual correction is performed UGA, high flexibility and high correlation with postoperative correction was also reported. However, this method is still not widely used considering less standardized correction force, complex implementation and preoperational arrangement.

This review might have some limitations. The heterogeneity among studies, such as inconsistent assessment methods and studied parameters, makes it difficult to conduct statistical analyses and draw solid conclusions. Besides, the methodology applied in the studies are quite diversified and most studies are cohort studies rather than RCT studies due to ethical issues. The reproducibility and reliability of some newly-developed methods for spinal flexibility assessment have not been studied.
Reference


Figure 1. Flow Diagram of the Study Procedure

Studies identified through database searching (n=81)

Studies after duplicates removed (n=82)

Studies screened (n=82)

Studies excluded based on title and abstract (n=66)

Full-text studies assessed for eligibility (n=16)

Full-text articles excluded: Retrospective study (n=1)

Studies included (n=15)
Table 1. Methodological Index for Non-Randomized Studies (MINORS) for Assessing Methodological Quality

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