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 contemporary spinal flexibility assessment methods on the patients with adolescent idiopathic scoliosis (AIS).

Summary of Background Data: Spinal flexibility is one of the essential parameters for clinical decision on the patients with AIS. Various methods such as side bending are proposed to assess the spinal flexibility, but whether they can reveal flexibility and predict postoperative correction is still unclear.

Methods: The databases of AbleData, IBSS, Academic Search Premier, MEDLINE/PubMed, CINAHL, Native Health Databases, CIRRIE, RECAL Legacy, Compendex, REHABDATA, EMBASE, Global Health and Web of Science were searched. The study inclusive criteria were: (1) prospective cohort study; (2) assessed spinal flexibility on the patients with AIS; (3) published in English 1996-2016.

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

Conclusions: Curve magnitude and location are important consideration when selecting a method to assess spinal flexibility and predict postoperative correction. The traction methods could be suggested for the patients with severe curves, while the lateral bending methods for the patients with moderate curves. Fulcrum bending could be recommended to assess main T curve flexibility whereas the supine with lateral bending for the proximal T or 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: 3

Key Points

1. Eleven methods are introduced for spinal flexibility assessment in this study.

2. Patients with different curve magnitudes and locations should select different methods for spinal flexibility assessment and postoperative correction prediction.

3. A comprehensive guideline for selecting spinal flexibility assessment method(s) need to be established via future studies.

Mini Abstract

Spinal flexibility is one of the essential parameters for clinical decision on the patients with AIS. This study reviewed eleven contemporary methods of spinal flexibility assessment, and suggested to select different methods for different patients according to their curve magnitude and location, for better revealing spinal flexibility and predicting postoperative correction.

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional (3D) deformity of the spine and rib cage, which occurs predominantly in peri-pubertal girls [1]. It is generally diagnosed with postero-anterior and lateral radiographies using the Cobb angle (angle between the two most tilted vertebrae of a spine segment) [2]. The prevalence of scoliosis ranges 2–3% [3]. Currently, the standard care for AIS includes: observation, for patients with small curve or skeletal maturity; brace treatment, for those with moderate curve and skeletal immaturity; and operation, for those with severe curve [4].

Spinal flexibility describes the mathematical ratio between the displacement of the spine and the force vector applied to generate this motion [5]. However, direct and quantitative assessment of the force and displacement on the spine may not be feasible. The current clinical practice is to assess the curve change along the change of body postures/correction force. That is, comparing the Cobb angle in standing posture with that in other corrected postures or under other reduction of forces, the correctability of the Cobb angle along the posture/force change is defined 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, prone with manual correction, etc.) emerge in recent years. Among these methods, which method(s) could reveal higher accuracy of spinal flexibility or could 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 the corresponding treatment effect.

Materials and Methods

Searching Strategy

The databases of AbleData, IBSS, Academic Search Premier, MEDLINE/PubMed, CINAHL, Native Health Databases, CIRRIE, RECAL Legacy, Compendex, REHABDATA, EMBASE, Global Health and Web of Science were searched. 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.

Various combinations of the key words "scoliosis", "flexibility", "reducibility" and "elasticity" were used to screen for potentially relevant studies. Original authors were contacted and asked to provide the full text of the potential papers if they were not accessible on-line or through university library.

Quality Assessment and Data Extraction

Quality Assessment

The Methodological Index for Non-Randomized Studies (MINORS) [6] 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. The first 8 items are specifically for non-comparative studies. All items have a “not reported”, “reported but inadequate” or “reported and adequate” answer option. The answer of “not reported” scored 0 point, “reported but inadequate” scored 1 point, and “reported and adequate” scored 2 points. Equal weights were applied, resulting in a maximum score of 16 points for the overall methodological quality score. For feasibility reasons, the assessment was not performed under masked condition.

The Cochrane Collaboration’s tool [7] was used to assess the risk of bias of included studies. Sequence generation, allocation concealment, blinding, completeness of outcome data, and absence of selective outcome reporting were assessed. Risk of bias was classified as low, high or not applicable in each domain.

In addition, the Oxford Centre for Evidence-Based Medicine 2011 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, results 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 the literature review.

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 were 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, 5 studies did not report subject recruitment method and 3 studies reported prospective recruitment of subjects without specifying whether the subjects were consecutive or not.

The results of the risk of bias assessment are presented in Table 2. Performance / detection bias, attribution bias and reporting bias were low for all included studies: the outcome and the outcome measurements were not likely to be influenced by lack of blinding; no missing outcome data; the study protocol was available and pre-specified (primary and secondary) outcomes that were of interest in the review have been reported in the pre-specified way. While the selection bias was high due to insufficient information about the sequence generation process and the participants assigned to different groups according to the characteristics of the disease (scoliosis curve magnitude and location).

The results of level of evidence assessment are presented in Table 3. Most studies are at evidence level 3.

Study Characteristics

Table 3 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) of 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. Five studies were compared with 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 postero-anterior standing radiograph and one study used antero-posterior standing radiograph, while the other three studies did not mention their methods. The sample size ranged from 5 to 127. Eight studies grouped patients / curves according to the curve magnitude and location. The other studies either grouped patients according to their surgical instrumentation methods 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[8] reported approximately 25% spinal flexibility in supine position.

(2) Lateral bending method

Nine studies [5,8-15] investigated supine or standing with lateral bending method. Two studies reported higher flexibility of moderate curves than severe curves [13,14]. Five studies reported higher flexibility of TL/L curves than T curves [8,9,13-15]. Eight studies assessed the fulcrum bending flexibility [8,9,11,12,14,16-18] and reported that the flexibility of T and TL / L were 45-74% and 53- 83% respectively.

(3) Manual correction method

Three studies investigated manual correction methods, which can be performed in supine or prone position. Two studies [13,14] investigated prone with manual correction method, one grouped curves according to magnitude (<60° or ≥60°) and location (T and TL/L) [13], one was according to the curve location only (T and TL / L) [14]. Moderate curve (<60°) was superior to severe curves (≥60°) 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) [13]. One study [12] assessed the supine with manual correction and found no significant difference for both main T curves and for the TL/L curves.

(4) Traction Method

Four studies [5,19,20] investigated standing with traction (suspension) method. Among which two studies grouped curves according to curve location [19]. The flexibility of T curve and TL / L curve were approximately 40% and 45% respectively. The other two studies [5,20] reported the overall reduction as 12-26° without grouping subjects. It was noticed that Hirsch et al. firstly attempted to use EOS system in the spinal flexibility assessment[19]. Two studies reported the supine with traction method [14,21] and three studies reported supine traction performed UGA [10,13,14], which proved the higher flexibility of supine traction UGA than without anesthesia (50-80% vs 28-56%) [14].

(5) Traction and manual correction method

Two studies [9,14] investigated supine traction and manual correction method. Main T and TL / L curves showed about 55%, 65% correction respectively. Two studies [12,17] investigated supine traction and manual correction performed UGA method. The curve can be corrected to approximately 40° (T curve) and 27° (L curve) in the studied subjects with general flexibility of approximately 55%.

Discussion

This study reviewed contemporary assessment methods of spinal flexibility on the patients with AIS. A total of fifteen studies (581 participants) were reviewed. Most of those studies are of evidence level 3 with a high methodological quality and low risk of bias. Eleven assessment methods (five 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. The comparison among different methods are shown in Table 4.

Spinal Flexibility Assessment

Supine with lateral bending method

Supine with lateral bending is commonly used for flexibility assessment clinically. Supine position reduces axial loading, lateral bending generates lateral correction forces, and exam bed exerts abdominal directed force to the spine, the combination effect of the three-dimensional forces may result in deformity correction. Severe curves were reported to be less flexible than moderate curves in supine with lateral bending test, 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 curve was reported less flexible than TL/L curve in this test, 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 due to patient's subjective efforts and decreased accuracy of postoperative prediction due to advancement of instrumentation. 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 could reveal higher spinal flexibility in both moderate (cobb<60°) and severe curves (≥60°) than supine with lateral bending [14,22,23]. It gave higher correction in T curves but similar correction in TL / L curves than supine with lateral bending [8]. 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 forces generated by the muscles during active lateral bending. Fulcrum bending method has replaced the supine with lateral bending radiograph as routine preoperative assessment in some institutions [23].

2. Supine method vs supine with lateral bending method

The supine and supine with lateral bending flexibility were reported as approximately 25% [8] and more than 40% [8,9,12-15,24] respectively. It is understandable that extra self-bending force may create correction and increase the flexibility.

3. Manual correction method vs supine with lateral bending method

Prone with manual correction may provide less correction than supine with lateral bending and less accuracy to predict the postoperative correction [25,26]. 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 [26], assess spinal balance via demonstrating the primary curve correction effect on both upper and lower curves [8], and expose patients to less radiation by 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 [12]. It might because the force applied by examiners could be better controlled, the correction is not easily affected by the curve location, pattern or etiology.

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 significantly lower flexibility than supine with lateral bending for curves over 45° [5]. Supine traction also showed lower flexibility than supine with lateral bending for curves less than 50°, whereas higher flexibility for curves over 60° [27]. These findings validated that higher correction could be achieved with axial loading for severe curves and with transverse loading for moderate curves [28,29]. When supine traction was performed UGA, the flexibility increased greater than supine with lateral bending, regardless of curve magnitude [10]. This indicated that patient's contraction and muscle spasm would strongly affect curve correction during flexibility assessment.

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

Traction and manual correction can be performed without anesthesia or UGA. Supine traction and manual correction without anesthesia revealed higher flexibility on main T curves, equivalent flexibility on TL / L curves than supine with lateral bending [9]. Supine traction and manual correction UGA showed greater flexibility than supine with lateral bending [12], also higher flexibility than fulcrum bending in severe patients (Cobb > 60°) [17]. 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. [30] reported the correlation of Cobb angle in supine with lateral bending with postoperation to be 0.81 and 0.41 in T and L curves respectively. King et al. [31] and Lenke et al. [32] 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 instrumentations. 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) [33]. Its inability to predict the correction of pedicle screws and CD system was reported as well [34,35]. For predicting postoperative correction accurately and avoiding unnecessary fusion, new methods emerged and was investigated these 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 [23]. To assess flexibility for T curves, the fulcrum bending demonstrated better 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 of no significant difference [8]. For moderate curves (40-65°), fulcrum bending gave higher correction than that of supine with lateral bending and traction UGA and better prediction of postoperative correction. For severe curves (>65°), the angle in traction UGA radiograph is closer to postoperative angle than that of fulcrum bending and supine with lateral bending radiographs [14].

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 correction (approximately 25% [8]) was far less than the aim of postoperative correction. No study was found to compare the supine method with supine with lateral bending method or adopt supine method to predict postoperative correction.

3. Manual correction method vs supine with lateral bending method

The Cobb angle on prone with manual correction radiograph is significantly larger than that on postoperative radiograph ($p=0.03$) [8,26], while the corrected Cobb angle was not statistically different (21.1° and 21.8° respectively) [25]. This difference might be due to different measurement parameters and / or different surgical instrumentations (Harrington versus Moss-Miami / Cotrel-

Dubousset instrumentation). Supine with manual correction method was reported to show similar correction with supine with lateral bending but both corrections were less than postoperative correction [12].

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 test to predict postoperative correction is unclear and deserves further investigation, considering its possibility to apply quantitative correction force and applicability to EOS. The supine traction and supine with lateral bending were reported to have equivalent ability to predict the postoperative correction [30]. In comparison, supine traction radiograph is advantageous in imaging the entire spinal column to evaluate the spinal balance, applicable to patient's upper T curves and patients with neuromuscular disorders [14,36]; supine with lateral bending radiograph is advantageous in determining LIV and evaluating mobility of each disc space in the L region [37]. Supine traction UGA was found closer to postoperative correction than supine with lateral bending (1.5° difference between the angle on supine traction UGA and postoperative correction; 15° difference between angle on supine with lateral bending and postoperative correction [10]) and the flexibility / correction of supine lateral bending, supine traction UGA and postoperation were 66%, 79%, 76% respectively [14]).

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

Traction and manual correction flexibility was slightly lower than that of the postoperative correction, but not statistically significant [9]. Comparing to supine with lateral bending, standing with traction (suspension) and fulcrum bending, traction and manual correction showed the highest predictability to postoperative correction [9], which might be due to higher correction to be achieved via dual effect of lateral and axial correction forces to the scoliotic spine. Traction and manual correction UGA showed high correlation with postoperative correction [12] and also higher correction than fulcrum bending in the patients with severe scoliosis (initial cobb >60°) [17]. Traction and manual correction UGA can reveal high flexibility that surgeons always seek for. However, this method is still not widely used considering complex implementation, less standardized correction force and cannot give good preoperational planning.

Conclusion

Curve magnitude and location are two important parameters in selecting appropriate assessment method for spinal flexibility and prediction of treatment effect. 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 higher T or TL / L curves flexibility. A comprehensive guideline for selecting spinal flexibility assessment method(s) should be established via future studies.

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Flow Diagram

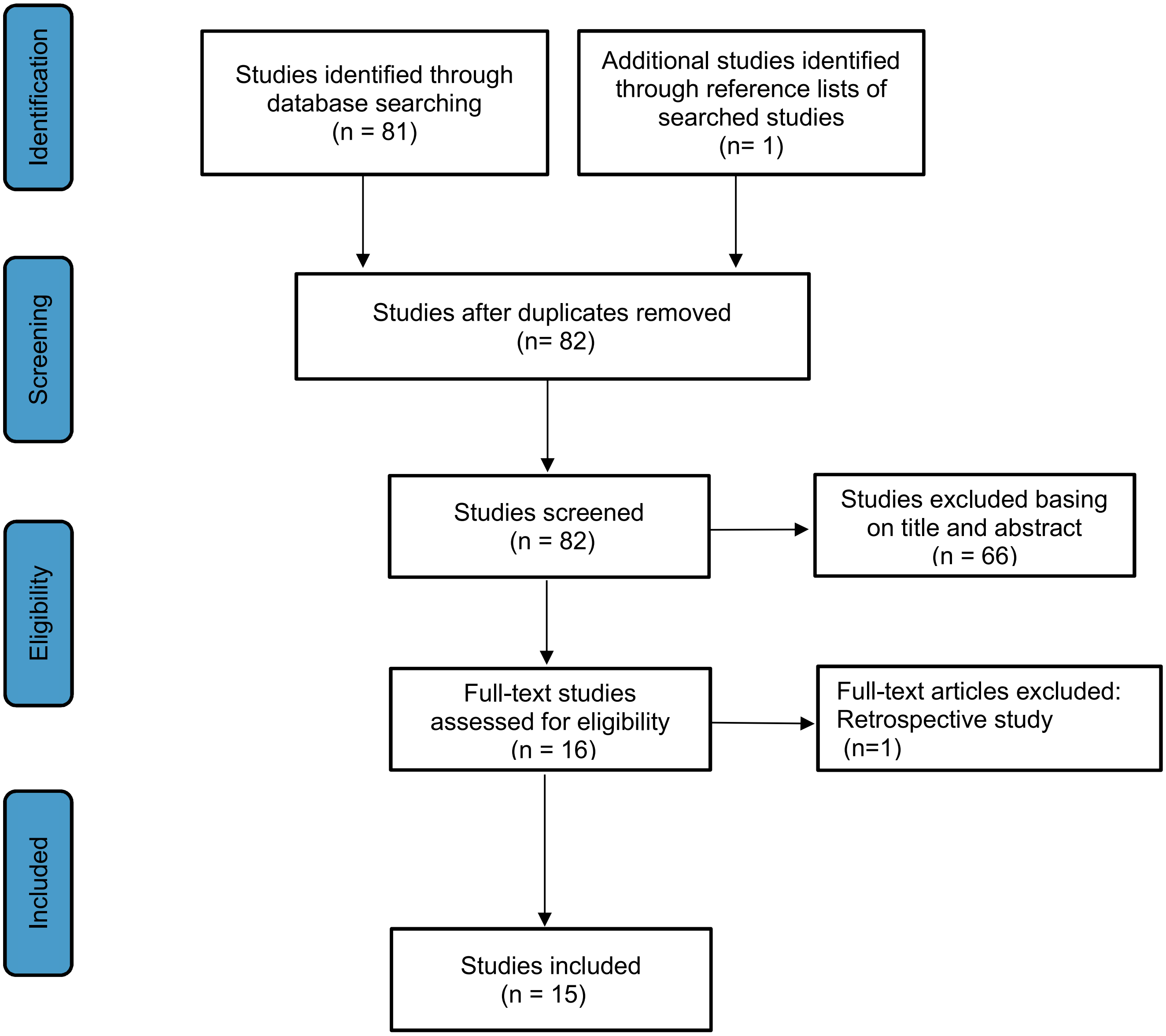

Figure 1: Flow Diagram of the Study Procedure

Table 1. Methodological Index for Non-randomized Studies (MINORS) for Assessing Methodological Quality

Items	Bu¨chler et al. 2014	Chen et al. 2011	Cheung et al. 2006	Davis et al. 2004	Hamzaoglu et al. 2005	Hirsch et al. 2015	Ibrahim et al. 2008	Klepps et al. 2001	Lamarre et al. 2008	Li et al. 2013	Liu et al. 2010	Luk et al. 2004	Rodrigues et al. 2014	Soucacos et al. 1996	Sun et al. 2013
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	0	2	1	0	2	2	1	2	1	1	2	2	2	1	1
3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total score	10	12	11	10	12	12	11	12	11	11	12	12	12	11	11

1. A clearly stated aim.
2. Inclusion of consecutive patients.
3. Prospective collection of data.
4. Endpoints appropriate to the aim of the study.
5. Unbiased assessment of the study endpoint.
6. Follow-up period appropriate to the aim of the study.
7. Loss to follow up less than 5%.
8. Prospective calculation of the study size.

The items are scored 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate). The global ideal score being 16 for non-comparative studies.

Table 2. The Cochrane Collaboration's Tool for Assessing Risk of Bias

Author, Year (reference)	Selection Bias		Performance/ detection bias	Attribution Bias	Reporting Bias	Others
	Sequence generation	Allocation concealment	Blinding of participants, personnel and outcome assessors	Incomplete outcome data	Selective outcome reporting	Other sources of bias
1. Bu¨chler et al. 2015	unclear	unclear	low	low	low	Small sample size
2. Chen et al. 2011	unclear	high	low	low	low	Not identified
3. Cheung et al. 2006	unclear	unclear	low	high	low	Small sample size
4. Davis et al. 2004	unclear	unclear	low	low	low	Not identified
5. Hamzaoglu et al. 2005	unclear	high	low	low	low	Not identified
6. Hirsch et al. 2015	unclear	unclear	low	low	low	Not identified
7. Ibrahim et al. 2008	unclear	high	low	low	low	Not identified
8. Klepps et al. 2001	unclear	high	low	low	low	Not identified
9. Lamarre et al. 2008	unclear	unclear	low	low	low	Not identified
10. Li et al. 2013	unclear	high	low	low	low	Not identified
11. Liu et al. 2010	unclear	high	low	low	low	Not identified
12. Luk et al. 2004	unclear	high	low	low	low	Not identified
13. Rodrigues et al. 2014	unclear	high	low	low	low	Not identified
14. Soucacos et al. 1996	unclear	high	low	low	low	Not identified
15. Sun et al. 2013	unclear	high	low	low	low	Not identified

Table 3. Characteristics of the Included Studies

Author/Year	Study Design	Level of evidence	Study Sample	Operation Type	Outcome Measures
1. Bu¨chler et al. 2015	Prospective cohort study	Level 3	n= 5 age=15±2	N/A	supine with lateral bending, suspension,
2. Chen et al. 2011	Prospective cohort study	Level 3	n=31 age=15	posterior fusion	supine with lateral bending, fulcrum bending, suspension, supine traction and manual correction,
3. Cheung et al. 2006	Prospective cohort study	Level 4	n=5 age=23 cobb=71°	anterior release & posterior fusion	fulcrum bending
4. Davis et al. 2004	Prospective cohort study	Level 3	n= 24 age=15 cobb=63°	posterior fusion; anterior release & posterior fusion	supine with lateral bending, supine traction UGA*
5. Hamzaoglu et al. 2005	Prospective cohort study	Level 3	n=37 age=16 cobb≥45°	posterior fusion	supine with lateral bending, fulcrum bending, supine with manual correction, supine traction UGA
6. Hirsch et al. 2015	Prospective cohort study	Level 3	n= 50 age=16±2 cobb=53°±11°	N/A	suspension, supine traction
7. Ibrahim et al. 2008	Prospective cohort study	Level 3	n=33 age=18 cobb=74°±9°	posterior fusion	fulcrum bending, supine traction and manual correction UGA,
8. Klepps et al. 2000	Prospective cohort study	Level 3	n=46 age=15	anterior or posterior fusion	supine, fulcrum bending, supine with lateral bending, prone with manual correction
9. Lamarre et al. 2009	Prospective cohort study	Level 3	n=18 age=16	N/A	standing with lateral bending, suspension
10. Li et al. 2013	Prospective cohort study	Level 3	n=17 age=16±2 cobb=48°±9°	posterior fusion	supine with lateral bending, fulcrum bending
11.Liu et al. 2010	Prospective cohort study	Level 3	n=58 age=14±2	anterior release & fusion and posterior fusion	supine with lateral bending, prone with manual reduction, supine traction UGA
12.Luk et al. 2004	Prospective cohort study	Level 2	n=127 age=15 cobb= 58°±10°	posterior fusion	fulcrum bending
13.Rodrigues et al. 2014	Prospective cohort study	Level 3	n=21 age=15	posterior fusion	supine with lateral bending, supine with manual correction, supine traction and manual correction UGA
14.Soucacos et al. 1996	Prospective cohort study	Level 3	n=39 age=12 cobb=58°	posterior fusion	supine traction
15.Sun et al. 2013	Prospective cohort study	Level 3	n=70 age =14±2 cobb=52°±6°	N/A	supine with lateral bending

* UGA： under general anesthesia

Table 4. Comparison among Spinal Flexibility Assessment Methods

Assessment methods		Correction force	Reproducibility	Radiation	Applicability	Easy operation	Flexibility
Supine Method	Supine	*	**	**	**	**	< SLB < operation
Lateral bending Method	Supine/stand with lateral bending	*	*	*	*	**	≈operation (traditional instrumentations) < operation (modern instrumentations)
	Fulcrum bending	*	**	*	*	**	> SLB ≈operation
Manual correction Method	Prone with manual correction	*	*	*	**	**	< SLB < operation
	Supine with manual correction	*	*	*	**	**	≈SLB < operation
Traction Method	Standing with traction (Suspension)	**	*	**	**	*	< SLB
	Supine traction	*	**	**	**	**	> SLB (initial cobb<50°) < SLB (initial cobb<50°)
	Supine traction UGA	*	**	**	**	*	> SLB ≈ operation
Traction & Manual correction Method	Supine traction and manual correction	*	**	*	**	*	> SLB ≈ operation
	Supine traction and manual correction UGA	*	*	*	**	*	> SLB ≈ operation

SLB: supine with lateral bending **UGA**: under general anesthesia **LIV**: last instrumented vertebrae
Correction Force: ** relatively standardized * less standardized
Reproducibility: ** relatively high * relatively low
Radiation: ** relatively low (one capture can show both structural curve and compensatory curve in the radiograph) * relatively high (at least two right and left side curve, or examiners may be exposed to radiation)
Applicability: ** can be applied to most patients with severe scoliosis * not applicable to less collaborative patients with severe scoliosis
Convenience: ** relatively simple implementation * relatively complicated implementation

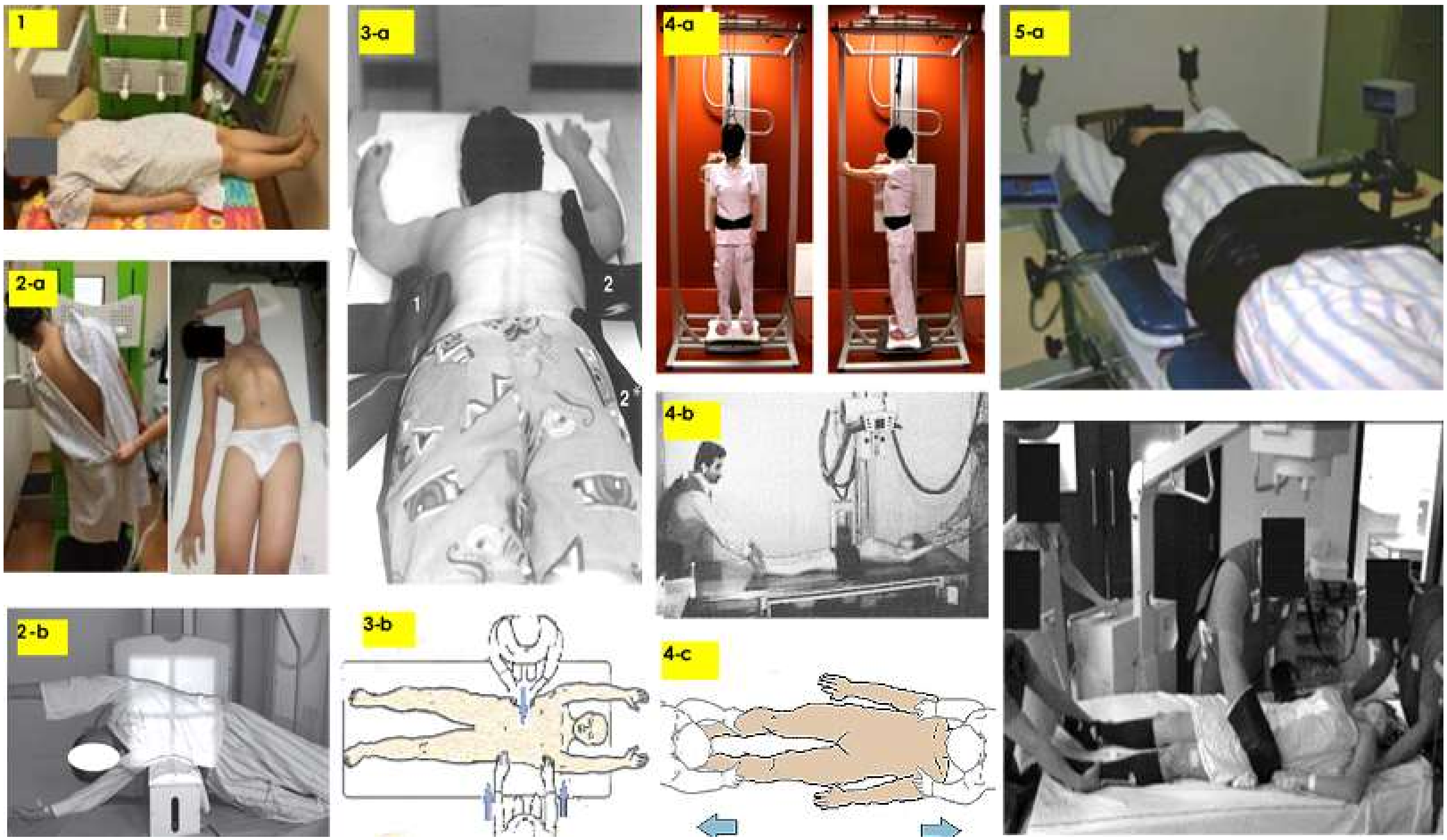

Figure 2. Methods of Spinal Flexibility Assessment
1 Supine 2-a Supine/stand with lateral bending 2-b Fulcrum bending 3-a Prone with manual correction 3-b Supine with manual correction 4-a Standing with traction (suspension) 4-b Supine traction 4-c Supine traction UGA 5-a Supine traction and manual correction 5-b Supine traction and manual correction UGA