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Subaraman Ramchandran
Nicklaus Children's Hospital

Ali Monsour
Nicklaus Children's Hospital

Alexander Mihas
Herbert Wertheim College of Medicine

Kevin George
Herbert Wertheim College of Medicine

Thomas Errico
Nicklaus Children's Hospital

See next page for additional authors

Authors

Subaraman Ramchandran, Ali Monsour, Alexander Mihas, Kevin George, Thomas Errico, and Stephen George

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Impact of Supine Radiographs to Assess Curve Flexibility in the Treatment of Adolescent Idiopathic Scoliosis

Subaraman Ramchandran, MD[1], Ali Monsour, MD[1], Alexander Mihas, BS[2], Kevin George, BA[2], Thomas Errico, MD[1], and Stephen George, MD[1]

Abstract

Study Design: Retrospective cohort study.

Objectives: The purpose of the study is to evaluate the role of supine radiographs in determining flexibility of thoracic and thoracolumbar curves.

Methods: Ninety operative AIS patients with 2-year follow-up from a single institution were queried and classified into MT structural and TL structural groups. Equations were derived using linear regression to compute cut-off values for MT and TL curves. Thresholds were externally validated in a separate database of 60 AIS patients, and positive and negative predictive values were determined for each curve.

Results: MT supine values were highly predictive of MT side-bending values (TL group: 0.63, $P < 0.001$; MT group: 0.66, $P = 0.006$). Similarly, TL supine values were highly predictive of TL side-bending values (TL group: 0.56, $P = 0.001$ MT group: 0.68, $P = 0.001$). From our derived equations, MT and TL curves were considered structural on supine films if they were $\geq 30°$ and 35°, respectively. Contingency table analysis of external validity sample showed that supine films were highly predictive of structurality of MT curve (Sensitivity = 0.91, PPV = 0.95, NPV = 0.81) and TL curve (Sensitivity = 0.77, PPV = 0.81, NPV = 0.94). ROC analysis revealed that the area under curve for MT structurality from supine films was 0.931 (SEM: 0.03, CI: 0.86-0.99, $P < 0.001$) and TL structurality from supine films was 0.922 (SEM: 0.03, CI- 0.84-0.98, $P < 0.001$).

Conclusions: A single preoperative supine radiograph is highly predictive of side-bending radiographs to assess curve flexibility in AIS. A cut-off of $\geq 30°$ for MT and $\geq 35°$ for TL curves in supine radiographs can determine curve structurality.

Keywords

adolescent idiopathic scoliosis, structural, supine radiographs, side-bending, flexibility

Introduction

Adolescent idiopathic scoliosis (AIS) is a tri-planar deformity of the spine and the rib cage. Surgical intervention is usually indicated if the primary curve exceeds 45°-50° because the long-term natural history of untreated idiopathic scoliosis dictates that such curves progress even after reaching skeletal maturity.[1-4] Surgery involves instrumentation and fusion of the involved spinal segments with a primary goal of halting the curve progression during periods of growth and achieving a stable well-balanced spine in the coronal and sagittal plane with minimum levels of fusion. Selective thoracic or lumbar fusion has shown to result in favorable long-term outcomes.[5-8] Conventionally, a decision to proceed with selective fusion depends on the ratio of the thoracic and lumbar curve magnitude and their respective flexibility as measured on supine side bending radiographs.[6,9] This is because if performed in

[1] Center for Spinal Disorders, Nicklaus Children's Hospital, Miami, FL, USA
[2] Florida International University Herbert Wertheim College of Medicine, Miami, FL, USA

Corresponding Author:
Subaraman Ramchandran, Department of Orthopedic Surgery, Nicklaus Children's Hospital, 3100 SW 62nd Avenue, Miami, FL 33155, USA.
Email: subbu_gsmc@yahoo.co.in

improperly selected patients, it can lead to decompensation of the unfused curves and progression of deformity.

Flexibility of a spinal curve has been traditionally determined by supine side-bending radiographs.[10-12] As has been previously reported, spinal flexibility differs in the proximal thoracic (PT), main thoracic (MT) and thoracolumbar (TL) regions.[11,13-15] Klepps et al reported that in order to achieve maximal preoperative correction, thoracic fulcrum-bending radiographs should be obtained for evaluating main thoracic curves, whereas side-bending radiographs should continue to be used for evaluating both upper thoracic and thoracolumbar/lumbar curves.[11] The major draw back of supine side-bending radiographs is that it is technician- and patient-dependent and can yield variable results depending on the curve type, apex of the deformity, and age of the patient.[16]

Various modalities to determine flexibility have been studied, showing variable flexibility, including side bending, push-prone, traction, and fulcrum bending. Therefore, it is important to choose one method that is simple, reproducible, not technician- or patient-dependent, and most importantly, reliable to assess spine flexibility. Although previous studies have reported the effectiveness of a single supine radiograph in determining curve flexibility, its current applicability is relatively unknown.[10,17] The purpose of this study is twofold: 1) to evaluate the role of a single supine radiograph in determining flexibility in structural MT and TL curves, and 2) to establish cut-off values in supine radiographs that determine the structurality of a curve separately for structural MT and TL curves.

Materials and Methods

Data Collection

An IRB approved retrospective review of data from operated AIS patients with minimum 2-year follow-up from a single institution was carried out. Patients were included if they had Lenke curve types of 1, 2, 5, or 6, along with availability of preoperative standing anteroposterior (AP) and lateral radiographs, and supine side-bending and supine AP radiographs. Non-AIS curve types, atypical curves and patients with previous fusions were excluded. Data collected included demographic parameters (age, sex, BMI, Risser) and radiographic measurements. Coronal Cobb angles were measured for PT, MT, and TL curves separately in standing, supine, and side-bending radiographs. Similarly, sagittal measurements including T2-T5 kyphosis, T5-T12 kyphosis, T10-L2 kyphosis and lumbar lordosis (L1-L5) were measured. Radiographic measurements were performed by dedicated spine research fellows and any discrepancies were confirmed by an attending spine surgeon. For supine side-bending radiographs, patients were instructed to relax, and left and right maximal passive side-bending was then performed by supervised, trained radiographic technicians. Based on Lenke classification, patients were divided into 2 groups: MT Structural (Lenke types 1 and 2) and TL Structural (Lenke types 5 and 6).

Statistical Analysis

Pearson correlation coefficients were determined between standing, supine, and side-bending radiographs for MT, and TL curves in each group. For the TL group, linear regression modeling was used to derive an equation demonstrating the relationship between TL Cobb angles on supine films and TL Cobb angles on side-bending films. Similarly, for the MT group, linear regression modeling was used to derive an equation demonstrating the relationship between MT Cobb angles on supine films and MT Cobb angles on side-bending films. These equations were then used to establish cut-off values for determining curve structurality on supine radiographs by computing the supine Cobb angle when the side-bending radiograph was 25°. A value of 25° was chosen as this is the current gold standard value on side-bending radiographs to determine structurality of any curve according to the Lenke classification.[12] Using a separate set of 60 AIS patients from our institution, these supine thresholds were externally validated via comparison to the Lenke classification, in which a structural curve was defined as $\geq 25°$ on side-bending radiographs. Receiver operating characteristic (ROC) curves were obtained, and cross tabulation was performed to determine positive and negative predictive values for each structural curve type. P-values of < 0.05 were considered significant. All statistics were conducted with SPSS 25 software.

Results

Ninety patients were included in the study with a mean age 15.5 years. For patients in TL group, MT and TL Cobb angles on supine radiographs were highly correlated with MT and TL side-bending values, respectively (MT Cobb: $r = 0.64$, $P < 0.001$; TL Cobb: $r = 0.56$, $P = 0.001$, Table 1). Using linear regression, the relationship between the TL Cobb angle on supine films (TL supine) and the TL Cobb angle on side-bending films (TL SB) was demonstrated by the following formula:

Similarly, for patients in MT group, MT and TL Cobb angles on supine radiographs were highly correlated with side-bending values (MT Cobb: $r = 0.66$, $P = 0.006$; TL Cobb: $r = 0.68$, $P = 0.001$, Table 2). Using linear regression, the relationship between the MT Cobb angle on supine films (MT supine) and the MT Cobb angle on side-bending films (MT SB) was demonstrated by the following formula:

Based on these derived equations using a side-bending value of 25°, MT and TL curves are considered structural when Cobb angles on supine radiographs are $\geq 30°$ and 35°, respectively.

Table 1. Correlation Between Supine, and Standing and Side-Bending Radiographs of Patients in the Structural TL Group.

Supine parameters	r, Standing	*P*-value	r, Side-bending	*P*-value
MT	0.799	0.000	0.635	0.000
TL	0.646	0.000	0.558	0.001

MT, main thoracic; TL, thoracolumbar

Table 2. Correlation Between Supine, and Standing and Side-Bending Radiographs of Patients in the Structural MT Group.

Supine parameters	r, Standing	*P*-value	r, Side-bending	*P*-value
MT	0.676	0.001	0.656	0.006
TL	0.534	0.005	0.679	0.001

MT, main thoracic; TL, thoracolumbar

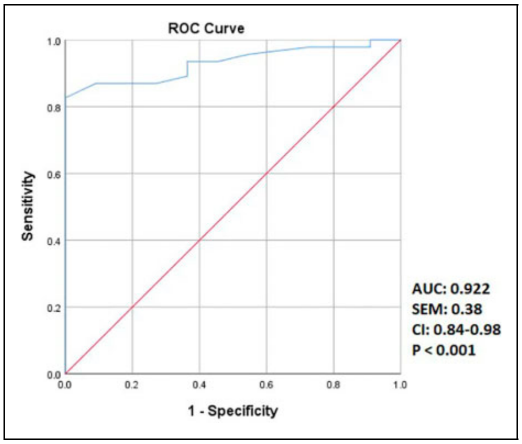

Figure 1. ROC curve for supine films predicting the structure nature of Tl curves.

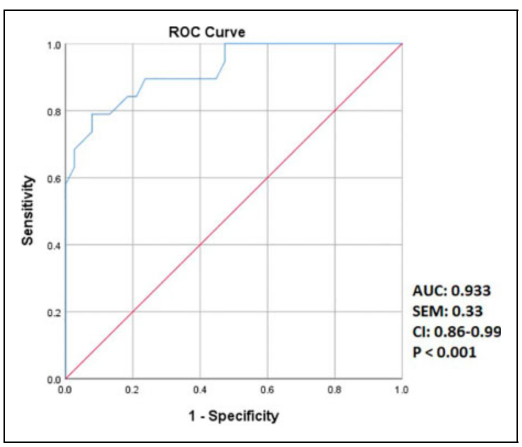

Figure 2. ROC curve for supine films predicting the structure nature of MT curves.

A separate database of 60 patients with operative AIS was used for external validity. Contingency table analysis of our external validity sample showed that supine films were highly predictive of the structural nature of the curves. In the TL group, supine radiographs demonstrated a high predictability of the structural nature of TL curves with cut-off values of $\geq 35°$ (Sensitivity = 0.77, positive predictive value [PPV] = 0.81, negative predictive value [NPV] = 0.94). Similarly, in the MT group, supine radiographs were highly predictable of the structural nature of MT curves with cut-off values of $\geq 30°$ (Sensitivity = 0.91, PPV = 0.95, NPV = 0.81). ROC analysis revealed that the area under curve (AUC) for supine films predicting the structural nature of TL curves was 0.922 (SEM: 0.03, CI: 0.84-0.98, $P < 0.001$, Figure 1). For predicting the structural nature of MT curves, the AUC was 0.931 (SEM: 0.03, CI: 0.86-0.99, $P < 0.001$, Figure 2).

Discussion

The primary goals of AIS surgery is maximal correction of the tri-planar deformity with the least number of fused segments leaving more mobile segments. It involves several correction maneuvers using segmental instrumentation. Selective fusion has been adopted by many surgeons especially after spontaneous correction of the unfused curves has been described in several studies.[9,18] Assessment of the flexibility of curves in AIS is essential to determine the structural nature of curves, hence selecting the proper instrumented levels. Furthermore, evaluating the flexibility of curves preoperatively helps to anticipate the response of curves to surgical correction and avoiding decompensation.[10]

Spine flexibility represents the ratio between the displacement of spine and the force applied to produce this change.[19] Clinically, it is defined as the percentage of change in Cobb angle between upright standing position and corrected posture or under reduction force.[20] Various methods have been used to assess the flexibility of compensatory curves. The use of AP side-bending radiographs is a standard method of accessing flexibility. The patient is asked to make a maximal effort when bending into and then away from the separate curves. Since this involves patient's voluntary efforts and technician guidance, it is subject to inconsistency.[10] Luk et al have advocated Fulcrum bending method for flexibility evaluation as this technique has been shown to be predictive of curve correction through posterior techniques.[21] Push-prone radiographs are also good method for accessing flexibility especially for patients who are unable to make a full bending effort.[22] However, these above techniques either involve the patient's voluntary effort or physician/technician skill and experience, and are therefore are subject to inconsistency. In addition, the ability of these preoperative radiographs to predict intraoperative correction is limited. The reduction force applied during these methods do not account for the intraoperative correction obtained through anesthesia, release of soft tissue, gravity, new technology of segmental instrumentation and powerful derotation and translation techniques.[10] Institutions implement different protocols in performing these examinations and this would prevent physicians from different hospital to compare the results and build a formidable multi-institution database.[23]

Supine radiograph on the other hand is a standard technique that is independent of patient cooperation and operator skills. It exposes the patient to less radiation since it involves only a single film to evaluate all the curves versus previously mentioned techniques.[11,21,22,24] In a study on AIS patients, Cheh et al showed that a single preoperative supine radiograph was highly predictive of side-bending films and even showed a better negative predictive value for determining structurality of the minor curves compared to side-bending radiographs.[10]

Our study is similar in methodology with that of Cheh et al. In addition, we have performed an external validation of our initial results on a separate database to improve the accuracy of our results. In our study, we determined that a correlation of magnitudes of thoracic and lumbar curves between supine and side-bending films for structural MT and TL curve types. Using this correlation, we calculated a new cut-off Cobb angle values on supine radiographs (30° for structural MT and 35° for structural TL). These values were externally validated in a separate database, and we found that for structural MT curves, the PPV was 0.95 and the NPV was 0.81 to predict structurality of MT curves. For structural TL curves, the PPV was 0.81 and NPV was 0.94 to predict structurality of TL curves. Furthemore, ROC analysis of supine radiographs as a utility to predict the structural nature of the curves revealed a high statistical significance and efficiency. Area under curve for supine films predicting the structural nature of curves was 0.931 for MT curves and 0.922 for TL curves.

There is no single way to assess the structural nature of a spinal curve in AIS. Our study is not proposing that supine radiograph be replaced for side-bending radiographs to determine flexibility. However, supine radiographs are an excellent modality to assess whether a curve is structural or not. The question arises to exactly define the role of flexibility x-rays in preoperative planning in AIS patients in today's era of powerful modern instrumentation and derotation techniques. The authors believe that the role of evaluating bending films is mainly twofold: 1) to evaluate the disc below the lower end vertebra in structural TL curves especially when there is a dilemma in choosing the LIV as L3 or L4 and 2) in severe long-standing rigid curves, to quantify the amount of flexibility, which cannot be determined by supine radiographs. Moreover, since thoracic and lumbar curves bend differently, a single cut-off value to determine their structurality is suboptimal.

Our study is not without limitations. Our sample size is relatively small, especially when considering performing external validity. Although the supine radiograph is a simple, standard method that can be used for preoperative planning of surgical instrumentation, it cannot quantify flexibility. Lastly, our study does not compare the use of supine radiographs with other established techniques like the push-prone or traction under GA for predicting curve flexibility. Nonetheless, supine radiographs show excellent predictability for determining the structural nature of a curve in AIS patients.

Conclusions

Our study demonstrates that a single preoperative supine radiograph is highly predictive of side-bending radiographs in assessing curve flexibility in patients with AIS. Furthermore, supine radiographs can determine curve structurality using cut-off values of $\geq$ 30° for MT curves and $\geq$ 35° for TL curves.

Authors' Note

Subaraman Ramchandran, MD: Conception and design, data acquisition, oversight, analysis, drafting, critical revision, and final approval. Ali Monsour, MD: Conception and design, data acquisition, analysis, interpretation, drafting, critical revision, and final approval. Alexander Mihas, BS: Data acquisition, interpretation, critical revision, and final approval. Kevin George, BA: Data acquisition, interpretation, critical revision, and final approval. Thomas Errico, MD: Data acquisition, interpretation, critical revision, and final approval. Stephen George, MD: Data acquisition, interpretation, critical revision, and final approval. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. IRB approval was obtained before the initiation of the study. Western Institutional Review Board, protocol number- 2019064RI.

Declaration of Conflicting Interests

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ORCID iD

Subaraman Ramchandran, MD https://orcid.org/0000-0001-7666-8574

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