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How well do we assess the adequacy of bending films in scoliosis?

INTRODUCING THE T1-45B METHOD FOR ASSESSING THE ADEQUACY OF BENDING FILMS

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Aims
To determine whether side-bending films in scoliosis are assessed for adequacy in clinical practice; and to introduce a novel method for doing so.

Methods
Six surgeons and eight radiographers were invited to participate in four online surveys. The generic survey comprised erect and left and right bending radiographs of eight individuals with scoliosis, with an average age of 14.6 years. Respondents were asked to indicate whether each bending film was optimal (adequate) or suboptimal. In the first survey, they were also asked if they currently assessed the adequacy of bending films. A similar second survey was sent out two weeks later, using the same eight cases but in a different order. In the third survey, a guide for assessing bending film adequacy was attached along with the radiographs to introduce the novel T1-45B method, in which the upper endplate of T1 must tilt ≥ 45° from baseline for the study to be considered optimal. A fourth and final survey was subsequently conducted for confirmation.

Results
Overall, 12 (86%) of 14 respondents did not use any criteria to assess the bending film adequacy; the remaining two each described a different invalidated method. In total, 12 (86%) of the respondents felt T1-45B was easy to learn and apply. There was fair to substantial intra-rater reliability (k = 0.25 to 0.88) which improved to fair to almost perfect (k = 0.38 to 0.88) post-introduction of the guide. Inter-rater reliability varied considerably among the rater groups but similarly increased following introduction of the guide (k_{S1} = 0.19 to 0.34, k_{S2} = 0.33 to 0.43 vs k_{S3} = 0.49 to 0.5, k_{S4} = 0.35 to 0.43).

Conclusion
Many surgeons and radiographers do not assess spinal bending films for adequacy. We propose that the change in the plane of the upper endplate of T1 on side-bending can be used in this evaluation. In the T1-45B method, a change of ≥ 45° on side bending qualifies as an adequate bend effort.

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Introduction
Achieving a spine that is balanced in the coronal and sagittal planes, and preventing curve progression, are the primary goals in the treatment of scoliosis. Treatment options include observation, bracing, and surgical fusion. Surgery is recommended in curves greater than 50° in skeletally mature patients, and curves greater than 45° in immature patients.[1] Side-bending radiographs are necessary for flexibility assessment and curve classification, and therefore fusion level selection.[2,3] While many techniques have been described, there is still no

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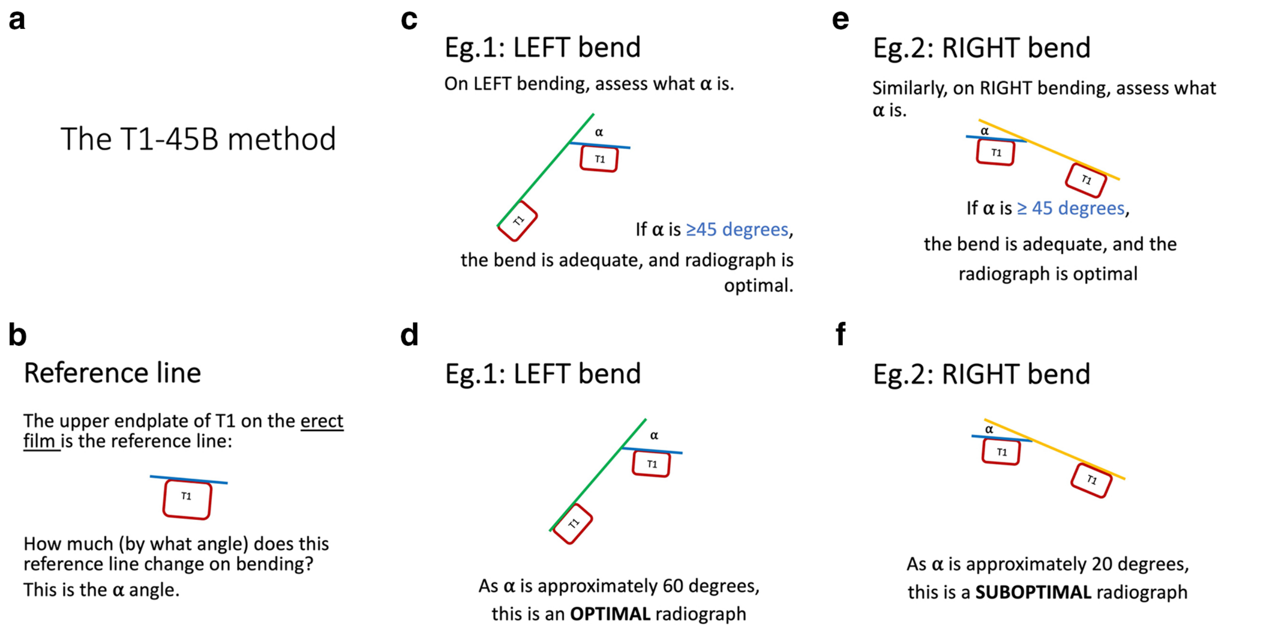

Fig. 1

a) and b) The reference line used in the T1-45B method. c) and d) An adequate left bend effort and optimal study. e) and f) An inadequate right bend effort and suboptimal study.

consensus on what constitutes an optimal method to assess the adequacy of bending when performing side-bending spinal radiographs.[4–8] Side-bending films are often readily accepted by radiographers and surgeons following their index acquisition without an adequacy check. This in turn directly impacts the choice of fusion levels which, if inappropriately selected, can potentially lead to a suboptimal clinical outcome from an unnecessarily long fusion, or in some other instances, 'adding on' or decompensation.[5] The challenge therefore lies in eliminating the subjectivity of what constitutes an adequate side-bending film, to help in the selection of fusion levels and surgical decision-making.

Bending films can also be used for clinical prognostication. Wong et al[9] showed in their systematic review that flexibility < 28% is a good predictor for curve progression in adolescent idiopathic scoliosis (AIS).

The objective of this study was first to determine the intra- and inter-observer reliability in the evaluation of adequacy of spinal bending films, and second, to propose a novel method for assessing the adequacy of bending films.

Methods

This study was approved by our healthcare cluster's institutional review board. A total of 21 medical professionals who routinely evaluate scoliosis films were invited to participate in four online surveys via institutional email. The group consisted of 11 fellowship-trained spine deformity surgeons and ten scoliosis radiographers from six tertiary centres in the Asia-Pacific region.

In the index survey, the erect posteroanterior (PA), left and right bending radiographs of eight individuals (mean age 14.6 years (SD 2.0)) with AIS were sent to the participants. All radiographs were performed by low-radiation slot scanning digital radiography. Respondents were asked to indicate whether each bending film was optimal or suboptimal based on their clinical judgment and experience. In the first survey (S1), participants were also asked to indicate if they used any specific criteria or method for assessing the adequacy of spinal bending films and, if so, the method employed. A similar second survey (S2) was sent out two weeks later, using the same eight cases but in a different, randomized order.

The 'T1-45B' method for assessing the adequacy of side bending radiographs. In the third survey (S3), a novel method (Figure 1a to f) for assessing the adequacy of spinal bending films was attached in the form of a six-page PDF guide. In the 'T1-45B' method, 'T1' represents the axis of the upper end plate of first thoracic vertebra and '45B' a tilt of 45° on side-bending. A side-bending film would be considered optimal if the upper endplate of T1 tilts ≥ 45° from the baseline on the erect film, while a T1 tilt of < 45° would be considered suboptimal. The upper end plate of T1 was highlighted with a blue line in all the radiographs in S3 to facilitate assessment of the bending angle (Figures 2a to c). In the fourth and last survey (S4), the novel guide was attached again, but the blue line highlighting upper end plate of T1 was removed from all radiographs (Figures 3a to c). All surveys were sent out at two-weekly intervals and the sequence of images was randomized for each survey.

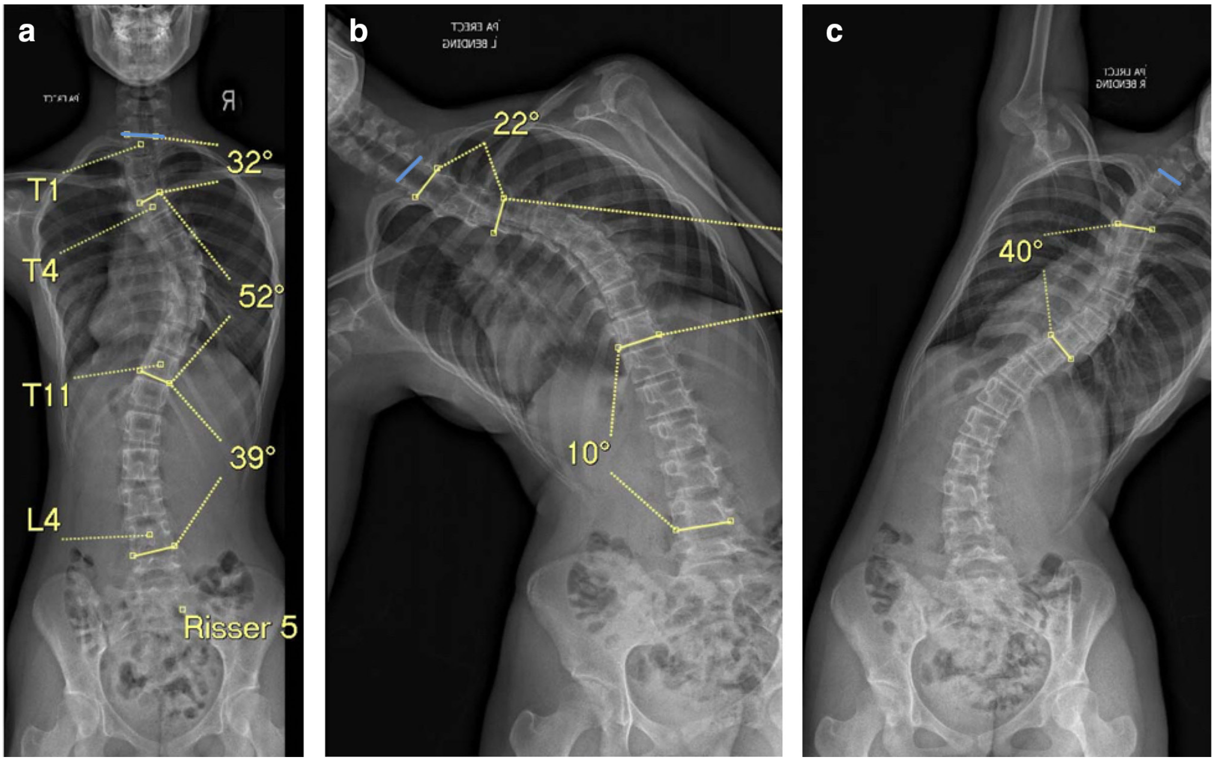

Fig. 2

a) Erect radiograph with upper endplate of T1 highlighted (for Survey 3). b) Optimal left bending radiograph. c) Suboptimal right bending radiograph.

To evaluate the understanding and applicability of the T1-45B method, we required participants to complete all four surveys. The responses from those who did not complete all four surveys were not included for analysis.

Statistical analysis. All data were analyzed using the SPSS software Version 19 (IBM, USA), unless othewise stated. A p-value of < 0.05 was considered statistically significant.

Inter-rater and intra-rater reliability were assessed by calculating the free marginal Kappa coefficient using an online Kappa Calculator.[10] The cut-off values for Kappa coefficient are: < 0 no agreement, 0 to 0.20 slight agreement, 0.21 to 0.40 fair agreement, 0.41 to 0.60 moderate agreement, 0.61 to 0.81 substantial agreement, and 0.81 to 1 almost perfect agreement.[8,11] No guidelines exist as to which level of agreement is acceptable.

McNemar's test was used to investigate the symmetry of disagreement with and without the T1-45B guide, which tests whether the frequency of a correct assessment, provided by raters with a guide, was significantly different from that without a guide. The participants' assessment of each of the 24 radiographs was scored as correct or incorrect against the gold-standard answers provided by a study team member using the guide.

Results

In total, 14 participants, comprising six fellowship-trained spine deformity surgeons and eight radiographers, completed all four surveys. A total of 896 responses were analyzed (14 participants × 4 surveys × 8 patients × 2 bending films per patient). The erect and side-bending radiographs of eight patients were used in the four surveys. A summary of their radiological measurements and Lenke classifications are summarized in Table I.

Overall, 12 of 14 participants (86%) reported they did not assess bending radiographs for adequacy, and accepted them as performed. The remaining two participants shared they did assess bending films for adequacy: one surgeon used the "distance between the iliac crest and ipsilateral floating ribs", while one radiographer "used the upright film as a guide" and ensured that "the pelvis and hips have a similar appearance on the bending film as the erect film." Neither participant elaborated further.

Intra-rater reliability. Before the T1-45B method was introduced to study participants, intra-rater reliability among surgeons was fair to substantial, with kappa values ranging from 0.25 to 0.75. Intra-rater reliability among radiographers was fair to almost perfect, with kappa values ranging from 0.25 to 0.88 (Table II).

After the T1-45B method was introduced, intra-rater reliability among surgeons and radiographers was noted as fair to almost perfect, ranging from 0.38 to 0.88.

Inter-rater reliability. Inter-rater reliability without (S1 and S2) and with (S3 and S4) the T1-45B guide are shown in Table III.

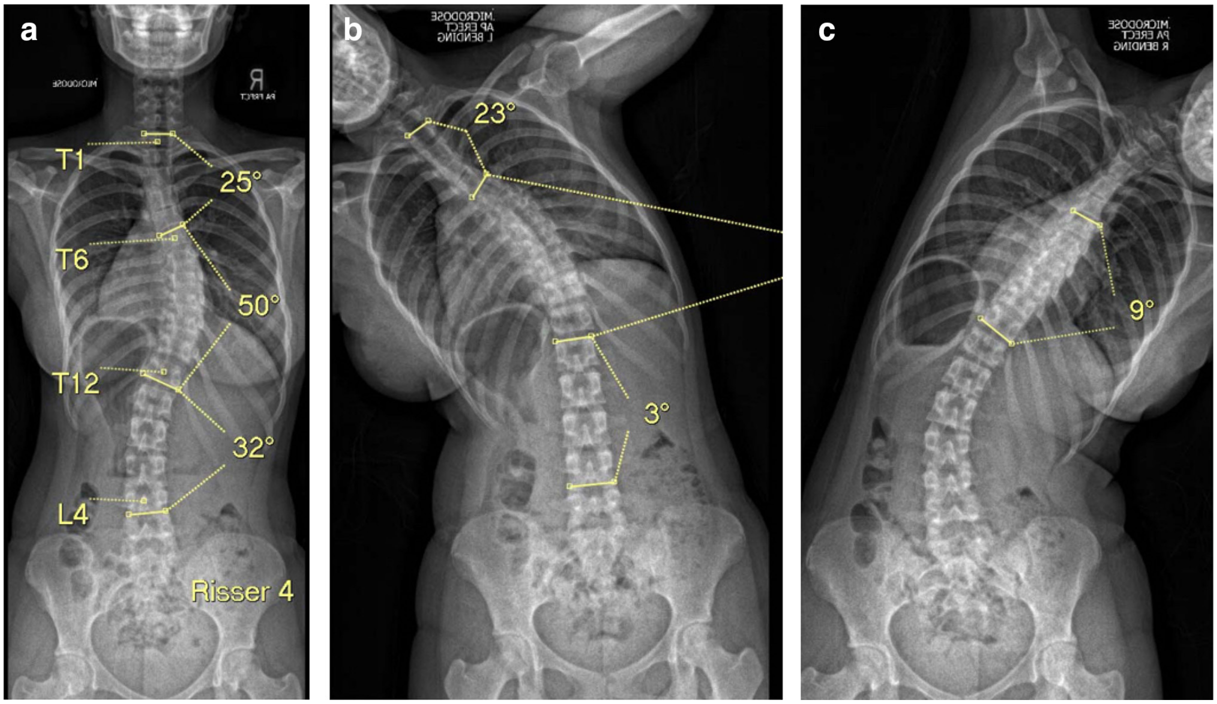

Fig. 3

a) Erect radiograph (for surveys 1, 2, and 4). b) Suboptimal left bending radiograph. c) Optimal right bending radiograph.

In general, inter-rater reliability varied across the two rater groups. In S1, their kappa values were interpreted as slight to fair, ranging from 0.19 to 0.34. Kappa values increased and was considered fair in survey 2, ranging from 0.33 to 0.43.

In S3, when the upper end plate of T1 was highlighted with a blue line in all the radiographs to facilitate assessment of bending angle, there was a further increase in inter-rater reliability to moderate agreement, with kappa values ranging from 0.49 to 0.51. When the raters were tested again without the blue line in S4, inter-rater reliability dropped slightly and was considered fair to moderate, with kappa values ranging from 0.35 to 0.43.

The McNemar's test was used to test whether the T1-45B method was useful in changing the participants' assessments from incorrect to correct. This test considers the possibility of a participant randomly modifying their assessment from incorrect to correct and vice versa. If the guide was useful, we hypothesized that the count of correct assessments in S4 (without the line highlighting upper end plate of T1) would be significantly higher than the count of incorrect assessments in S1 (first attempt). Our results in Table IV show that when compared to S1, there was a statistically significant increase in correct assessments in S4, after an initial incorrect assessment (19 vs 47) ($p < 0.001$, McNemar's test).

The count of correct and incorrect assessments in both S1 and S4 was irrelevant to this comparison.

Discussion

Although spinal bending films play an integral role in the surgical management of scoliosis, there is at present no validated method to evaluate their adequacy. Erect side-bending radiographs should be assessed and rejected if inadequate, as suboptimal bending radiographs may mislead surgeons during preoperative planning, and result in a fusion that is longer than necessary.[4] Several studies have highlighted the challenges in performing side-bending spinal radiographs. Oetgen et al[12] assessed the type and quality of imaging obtained before referral for specialist evaluation. They found many missing or inadequate radiographs, leading to repeat radiation exposure. Soultanis et al[13] and Hirsch et al[14] reported that a lack of patient cooperation during lateral bending led to inadequate radiographs and assessment of curve flexibility. In turn, several studies have proposed methods to standardize and optimize the acquisition of the side bending spinal radiograph. Mishra et al[15] described a simple yet effective three-point support technique to achieve adequate bending radiographs using slot scanning digital radiography. He and Wong[16] concluded that curve magnitude and location are two important parameters in selecting the appropriate method for spinal flexibility assessment; they suggested traction method for severe curves, lateral bending method for moderate curves, fulcrum bending method for thoracic curves, and supine with lateral bending method for thoracolumbar and lumbar curves.

Table I. Radiological measurements and Lenke classification of the eight cases used in the four surveys.

Variable	Value
Mean major curve Cobb angle, ° (SD)	56 (9)
Apex of the major curve, n (%)	
T8	2 (25)
T9	4 (50)
T11	1 (13)
L2	1 (13)
Mean thoracic kyphosis, ° (SD)	21 (6)
Risser stage, n (%)	
4	6 (75)
5	2 (25)
Lenke classification, n (%)	
1AN	2 (25)
1BN	3 (38)
2AN	1 (13)
2CN	1 (13)
6CN	1 (13)

SD, standard deviation.

Table II. Results of the intra-rater reliability assessment (kappa with 95% confidence intervals).

Rater	Without guide	With guide
Surgeon 1	0.25 (-0.24 to 0.74)	0.63 (0.23 to 1.00)
Surgeon 2	0.5 (0.06 to 0.94)	0.5 (0.06 to 0.94)
Surgeon 3	0.75 (0.42 to 1.00)	0.63 (0.23 to 1.00)
Surgeon 4	0.75 (0.42 to 1.00)	0.38 (-0.09 to 0.84)
Surgeon 5	0.75 (0.42 to 1.00)	0.88 (0.63 to 1.00)
Surgeon 6	0.75 (0.42 to 1.00)	0.38 (-0.09 to 0.84)
Radiographer 1	0.25 (-0.24 to 0.74)	0.63 (0.23 to 1.00)
Radiographer 2	0.38 (-0.09 to 0.84)	0.5 (0.06 to 0.94)
Radiographer 3	0.63 (0.23 to 1.00)	0.5 (0.06 to 0.94)
Radiographer 4	0.75 (0.42 to 1.00)	0.88 (0.63 to 1.00)
Radiographer 5	0.88 (0.63 to 1.00)	0.63 (0.23 to 1.00)
Radiographer 6	0.88 (0.63 to 1.00)	0.5 (0.06 to 0.94)
Radiographer 7	0.88 (0.63 to 1.00)	0.38 (-0.09 to 0.84)
Radiographer 8	0.88 (0.63 to 1.00)	0.75 (0.42 to 1.00)

Table III. Results of the inter-rater reliability assessment (kappa with 95% confidence intervals).

	Rater group	
Survey	**Surgeons**	**Radiographers**
Survey 1 (without guide)	0.19 (-0.03 to 0.41)	0.34 (0.15 to 0.54)
Survey 2 (without guide)	0.43 (0.18 to 0.67)	0.33 (0.12 to 0.53)
Survey 3 (with guide)	0.49 (0.25 to 0.73)	0.51 (0.27 to 0.75)
Survey 4 (guide removed)	0.43 (0.25 to 0.67)	0.35 (0.13 to 0.57)

Table IV. McNemar's test for the proportion of correct answers with and without the T1-45B guide. p-values were < 0.001 for all variables.

	With guide		
Without guide	**Incorrect**	**Correct**	**Total**
Incorrect	66	47	113
Correct	19	92	111
Total	85	139	224

Of the 14 participants, 12 (86%) agreed that the T1-45B method was useful, readily learnt, and applicable to their clinical practice.

We believe there is a need for a simple and reproducible method that can be applied easily in clinical practice to assess the adequacy of side-bending films. In conceptualizing the T1-45B method, we selected the superior endplate of T1 as the principal reference landmark, as it is readily identifiable on posteroanterior radiographs, even when micro-dose protocols are used in slot-scanning digital radiography. In addition, a tilt of 45° on bending was selected since one can readily draw or visualize a 45° angle from a reference line. The T1-45B can be applied to bending radiographs acquired in supine[5–7] or standing positions.[15] Of the 14 participants from the survey, 12 (86%) agreed that this method was useful, easy to learn, and immediately applicable to their clinical practice.

The increase in kappa values after the introduction of the guide in S3 indicates a decreased variability in the responses to the survey. The baseline intra-rater reliability was initially fair to substantial (0.25 to 0.88), but improved to fair to almost perfect (0.38 to 0.88) upon introduction of the T1-45B method. Baseline inter-rater reliability varied considerably among the rater groups. Differences in the backgrounds and experiences of the raters were considered potential factors affecting the levels of agreement. Nonetheless, inter-rater reliability improved from the respective baselines following introduction of T1-45B.

McNemar's test showed a statistically significant change in responses before and after the introduction of the guide ($p < 0.001$). The proportions of correct answers after an initial wrong answer were derived from the 2 × 2 contingency table (Table IV), and showed that use of the T1-45B method resulted in an increased number of correct answers. While we acknowledge that the level of experience of the raters does influence the intra- and inter-rater variability, we also believe that spine deformity surgeons and radiographers routinely performing and evaluating scoliosis radiographs will be able to apply the guide more efficiently and effectively with regular practice.

Finally, in addition to the unnecessary inclusion of spinal levels in the fusion construct, inadequate films may also lead to increased healthcare costs and increased radiation exposure when the additional films must be taken due to suboptimal radiographs. The increased radiation exposure is particularly undesirable in paediatric patients. In addition, patients with scoliosis often undergo radiographs at regular intervals during their treatment.[17–21] A higher incidence of breast, thyroid, and other cancers has been reported in patients with repeated exposures to plain radiographs.[19,20]

This study has several limitations. First, the number of participants in the survey was small; the aim and design of the study required participants to complete all four surveys over a period of six weeks. Nonetheless, the 896 responses from the 14 participants who completed all four surveys was sufficient to run a meaningful analysis.

In addition, we acknowledge there is a degree of subjectivity when determining the point at which the upper endplate of T1 tilts ≥ 45° from baseline on the erect film from eyeballing the radiographs alone. This limitation is also highlighted by the observation that the highest inter-rater reliability of moderate agreement (kappa values 0.49 to 0.51) was recorded in S3 when the upper end plate of T1 was highlighted with blue line. However, when the same raters were tested again without the blue line in S4, inter-rater reliability dropped slightly to fair to moderate (kappa values 0.35 to 0.43). We postulate that one reason could be that since the surveys were distributed via email, some participants may have used their mobile phones to assess the films, which may have affected the accuracy of the assessment. This, however, is pure speculation on our part. In clinical practice, we believe radiographs are always read on a monitor and never on a mobile phone.

To summarize, although side-bending spinal radiographs play an integral role in the preoperative planning of AIS patients, many surgeons and radiographers do not routinely assess the adequacy of these films following their acquisition. One reason for this could be the lack of a simple method for assessment. We advocate that the T1-45B method can be used to assess the adequacy of side-bending films, which will in turn help surgeons classify scoliosis curves and select spinal fusion levels more accurately. This T1-45B method will need to be validated in future studies.

Take home message

- Side-bending films performed for flexibility evaluation of scoliosis are generally not assessed for adequacy.
- In the proposed T1-45B method, we advocate that a side-bending radiograph is optimal if the upper endplate of T1 tilts ≥ 45° from the baseline on the erect film.
- Conversely, a tilt of < 45° is suboptimal.

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