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ORIGINAL ARTICLE

Calculation of corrected body height in idiopathic scoliosis: comparison of four methods

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Abstract
Purpose The aim of the study was to analyze four radiographic methods of calculating the loss of body height associated with scoliosis.
Methods Thirty patients with right thoracic idiopathic scoliosis were examined with standing postero-anterior radiographs. Cobb angles of the upper thoracic, main thoracic and lumbar curves were measured. The loss of body height due to scoliosis was measured directly on the radiographs and then calculated using the methods of Bjure, Kono, Stokes and Ylikoski, respectively. The reproducibility of calculations was tested. Detailed analysis of two patients with similar Cobb angle but different trunk height was performed.
Results The mean Cobb angle of the main thoracic curve was 46° (21°–74°). The mean loss of body height was 23 mm (11–43 mm) calculated by method of Bjure, 7 mm (−24 to 46 mm) by Kono, 20 mm (5–47 mm) by Stokes, 14 mm (3–36 mm) by Ylikoski, versus 18 mm (3–50 mm) measured directly on radiographs. The overall difference between the loss of body heights was significant ($p < 0.0001$), with significant differences in pairs for: Bjure versus Kono ($p < 0.0001$), Stokes versus Kono ($p = 0.0002$), Kono versus measured ($p = 0.0061$) and Bjure versus Ylikoski ($p = 0.0386$). Strong linear correlation between the methods was found ($r \geq 0.92$; $p < 0.0001$). High reproducibility of height loss calculations was noticed. The two patients with similar Cobb angle and different trunk height revealed similar height loss calculated, while different loss measured on radiographs.
Conclusions There existed no overall agreement between the four methods of calculation of the loss of body height associated with scoliosis. Calculations based on the Cobb angle produced inaccuracy and could be supplemented with data considering trunk size.

Keywords Idiopathic scoliosis · Body height · Cobb angle · Radiograph

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Introduction

Total body height in patients with scoliosis is diminished due to the spinal deformity. Corrected body height is needed to establish various clinical parameters such as normal values of blood pressure in children, lungs vital capacity (VC), growth charts, and body mass index (BMI) [1–6]. In 1968, Bjure et al. [7, 8] developed an empirically based formula employing the Cobb angle for predicting proper body height in scoliotic patients. Independently, Kono et al. [9], Ylikoski [10] and finally, Stokes [11] presented approaches consisting of regression analysis of the radiological data for calculating the corrected body height in scoliotic patient. All of these methods relied on the Cobb angle to predict the true body height in patients with scoliosis. All methods employ sophisticated mathematical formulas which make their use in everyday clinical practice cumbersome. Potential for inaccuracy of the methods has been reported, because none of them consider the actual height of the subject with scoliosis [12]. In spite of this hypothesized limitation the methods are being used to calculate BMI or VC of patients with scoliosis [2, 5, 13, 14]. None of the methods is considered as a gold standard for calculating the corrected body height in scoliotic individuals. No published data comparing the various methods of calculating the corrected body height in patients with scoliosis was found.

The aim of this study was to use a homogenous set of patients with right thoracic idiopathic scoliosis (IS) to compare the Bjure, the Kono, the Stokes, and the Ylikoski method of calculating corrected body height. We describe reproducibility, and advantages, disadvantages and potential limitations of each method [7–11].

Materials and methods

After having obtained institutional review board approval, a group of 30 patients with right thoracic IS, examined between January 2010 and May 2013 with standard standing long-cassette postero-anterior digital radiographs (General Electric Medical Systems, Centricity PACS Radiology RA1000 Workstation), were retrospectively enrolled into the study. There were 28 females and 2 males, with a mean age of 13 years (10–18 years).

Three series of measurements were performed by one researcher (orthopedic spine surgeon with 8 years of practice) at 1 week intervals. The Cobb angle of each curve, both structural and compensatory, was measured. The loss of body height associated with IS was calculated by use of four methods for each series of measurements.

Bjure et al. method

To calculate the loss of body height (Y, in cm) due to IS according to Bjure et al. the following formula was used:

$$\text{Log}Y = 0.011X - 0.177$$

where X is the Cobb angle of the major curve [7, 8].

In this study, the value of the Cobb angle of the biggest curve in each of 30 patients was taken into account.

Kono et al. method

According to the method of Kono et al. the loss of body height due to IS (Y, in mm) was calculated by use of the formula:

$$Y = 0.6X + 2.6$$

where $X = \sum(\text{Cobb} - 30) = (\text{Cobb1} - 30) + (\text{Cobb2} - 30) + \cdots + (\text{Cobb}n - 30)$.

In this study, all the curves, structural and compensatory, were considered for each patient [9].

Stokes method

Following Stokes, the formula,

$$Y = 1.55 - 0.0471\text{Cobb} + 0.009\text{Cobb}^2,$$

was used to calculate the loss of height (Y, in mm) in all 30 patients [11].

In this study, the value of the Cobb angle of the biggest curve in each of 30 patients was considered.

Ylikoski method

In 2003, Ylikoski proposed his formula to calculate the loss of body height due to curve in the coronal plane and corrected also by sagittal plane abnormalities [10]. In the recent study, the influence of the lateral curve on body height was considered and the loss of height (Y, in mm) was calculated according to the formula:

$$Y = 0.0062x + 0.0024x^2$$

where x = Cobb angle of major curve + Cobb angle of minor curve (in degrees).

In this study, for each of 30 patients, the Cobb angle of the main thoracic and the lumbar curve was taken into account to calculate the loss of height.

All calculations were performed using Microsoft Office Excel 2007. The loss of height calculated by use of each method was given in millimeters (mm).

The T1–S1 height of the spine and the T1–S1 length of the spine were measured for each of 30 patients. The T1–S1 height of the spine was defined as the straight vertical distance between the level of the midpoint of the T1 proximal endplate and the level of the midpoint of the S1 proximal endplate, Fig. 1. The T1–S1 length of the spine was measured along the curved line starting at the midpoint of the T1 proximal endplate, crossing the centroids of T1–L5 vertebral bodies and reaching the midpoint of the S1 proximal endplate (Fig. 1) [7–11]. The loss of body height was calculated as the difference between the T1–S1 spinal length and the T1–S1 spinal height. This value was considered as the "measured" loss of height.

To compare the loss of height calculated by use of Bjure, Kono, Stokes and Ylikoski methods and the measured loss of height, the analysis of variances (ANOVA) and post hoc Tukey HSD test were used. Correlation for each pair of methods was quantified by the Pearson's linear correlation coefficient (r).

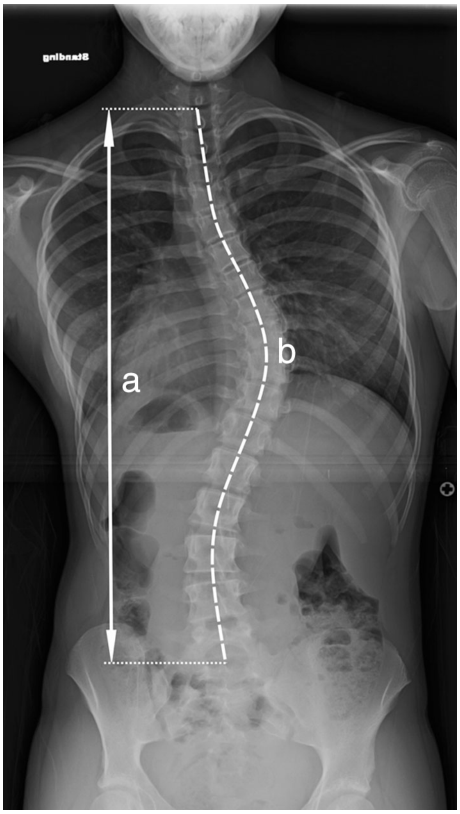

Fig. 1 Standing postero-anterior radiograph of a patient with idiopathic scoliosis. **a** The T1–S1 height of the spine, defined as the vertical distance between the level of the midpoint of the T1 proximal endplate and the level of the midpoint of the S1 proximal endplate; **b** T1–S1 length of the spine measured along the curved line starting at the midpoint of the T1 proximal endplate, crossing the centroids of T1–L5 vertebral bodies and reaching the midpoint of the S1 proximal endplate

The intraobserver reproducibility for calculating the loss of body height according to each method as well as for Cobb angle measurements was quantified by the intraclass correlation coefficient (ICC) and the median error for the single measurement (SEM).

Three researchers (orthopedic spine surgeons with 20, 10 and 8 years of practice) measured the Cobb angles independently on all 30 radiographs and calculated the loss of body height according to each of 4 methods tested using the same methodology. The interobserver reliability for calculating the loss of body height according to each method and for Cobb angle measurements was quantified by ICC and SEM.

The hypothesis that using the Cobb angle for calculating the loss of height associated with IS may reveal inadequate was verified as follows. Two patients with similar Cobb angle values of all the curves (Patient #24 and Patient #29) were selected. The calculated and the measured loss of height of these patients were compared.

The data were analyzed using the JMP 10.0.2 (SAS Institute Inc, Cary, NC) statistical software. The p level of 0.05 was considered significant. The Pearson's linear correlation coefficient (r) of less than 0.3 was considered as negligible correlation, 0.3–0.5 as low, 0.5–0.7 as medium, 0.7–0.9 as high, and 0.9–1.0 as very high correlation [15]. The ICC value >0.7 reflected acceptable reproducibility for a research tool [16].

Results

The total number of spinal curves considered in 30 patients was 90 (3 curves in each patient). The mean Cobb angle was 46° (range 21°–74°) for the major curve, 25° (range 11°–42°) for the upper compensatory curve, and 26° (range 12°–48°) for the lower compensatory curve. The mean loss of body height was: 23 mm (range 11–43 mm) calculated by method of Bjure, 7 mm (range −24 to 46 mm) by method of Kono, 20 mm (range 5–47 mm) by method of Stokes, 14 mm (range 3–36 mm) by method of Ylikoski, and 18 mm (range 3–50 mm) measured on radiographs (Table 1).

The difference between the loss of body height calculated using the 4 methods and the measured loss of height was significant ($p < 0.0001$) (Fig. 2). Comparing the pairs of methods the significant differences were noted between the following: Bjure versus Kono ($p < 0.0001$), Stokes versus Kono ($p = 0.0002$), Kono versus measured ($p = 0.0061$) and Bjure versus Ylikoski ($p = 0.0386$). The differences were not significant between the following: Ylikoski versus Kono ($p = 0.1224$), Stokes versus Ylikoski ($p = 0.2732$), Bjure versus measured ($p = 0.3853$), Ylikoski versus measured ($p = 0.8207$), Stokes versus measured ($p = 0.8872$) and Bjure versus Stokes ($p = 0.91$) (Table 2). There was a strong linear correlation between each pair of the methods ($r \geq 0.92$; $p < 0.0001$) (Table 2).

The ICC for intraobserver reproducibility of calculations of height loss was 0.98 with SEM of 1 mm for Bjure, 0.97 with SEM of 2 mm for Kono, 0.97 with SEM of 1 mm for Stokes, and 0.98 with SEM of 1 mm for Ylikoski (Table 3). The ICC for reproducibility of the Cobb angle measurement of the major curve was 0.94 with SEM of 2°.

The ICC for interobserver reliability of calculations of height loss was 0.95 with SEM of 1 mm for Bjure, 0.96 with SEM of 2 mm for Kono, 0.96 with SEM of 2 mm for Stokes, and 0.97 with SEM of 1 mm for Ylikoski (Table 3). The ICC for interobserver reliability of the Cobb angle measurement of the major curve was 0.95 with SEM of 2°.

The Cobb angles of the upper thoracic, main thoracic and lumbar curve of Patient #24 versus Patient #29 were: 24°, 48°, 29° versus 24°, 49°, 24°, respectively.

Table 1 Cobb angle and loss of body height associated with scoliosis calculated and measured for all 30 patients

Patient	Cobb angle			Loss of height calculated with method of:				Loss of height measured (mm)
	Proximal thoracic (°)	Main thoracic (°)	Lumbar (°)	Bjure (mm)	Kono (mm)	Stokes (mm)	Ylikoski (mm)	
1	34	50	20	23	11	21	12	20
2	37	45	17	21	8	17	10	11
3	15	51	35	24	9	22	18	23
4	23	51	36	24	15	22	19	23
5	34	44	21	20	8	17	11	14
6	22	43	29	20	5	16	13	16
7	34	63	38	33	29	34	25	31
8	17	37	21	17	−6	12	9	12
9	19	42	29	19	3	15	13	13
10	13	21	12	11	−24	5	3	3
11	16	45	24	21	0	18	12	15
12	27	39	27	18	5	14	11	8
13	22	34	18	16	−7	10	7	6
14	11	36	22	17	−10	11	8	9
15	31	46	20	21	6	18	11	9
16	27	44	27	21	7	17	13	8
17	32	69	31	38	28	41	25	28
18	32	73	38	42	34	46	30	41
19	19	54	42	26	18	25	23	26
20	22	46	26	21	5	18	13	23
21	42	73	48	42	46	46	36	50
22	35	74	44	43	40	47	34	38
23	30	48	24	23	10	20	13	19
24	24	48	29	22	9	20	15	14
25	20	33	27	15	−3	10	9	7
26	22	37	13	17	−8	12	6	9
27	13	28	15	13	−18	7	5	5
28	24	33	14	15	−9	10	6	8
29	24	49	24	23	7	20	13	22
30	22	37	21	17	−3	12	8	10
Mean	**25**	**46**	**26**	**23**	**7**	**20**	**14**	**18**
Range	**11–42**	**21–74**	**12–48**	**11–43**	**−24 to 46**	**5–47**	**3–36**	**3–50**

For the Patient #24, the Th1–S1 spine length was 393 mm while the Th1–S1 spine height was 379 mm thus giving the actual measured loss of body height of 14 mm (Fig. 3a). The loss of body height calculated by use of methods of Bjure, Kono, Stokes, and Ylikoski was 22, 9, 20, 15 mm, respectively.

For the Patient #29, the Th1- S1 spine length was 472 mm while the Th1–S1 spine height was 450 mm thus giving the actual measured loss of body height of 22 mm (Fig. 3b). The loss of body height calculated by use of methods of Bjure, Kono, Stokes, and Ylikoski was 22, 7, 20, 13 mm, respectively.

Discussion

We present the analysis of four radiographic methods of calculating the loss of body height associated with scoliosis. Even if these methods have been used in various studies to calculate the corrected body height in scoliotic patients, a comparison of the methods has never been performed by an independent research [2, 5, 13, 14].

The authors of each method developed mathematical formulas employing regression analysis of the relationship between the height loss and the Cobb angle (or Cobb angles). All four authors based their analysis on various

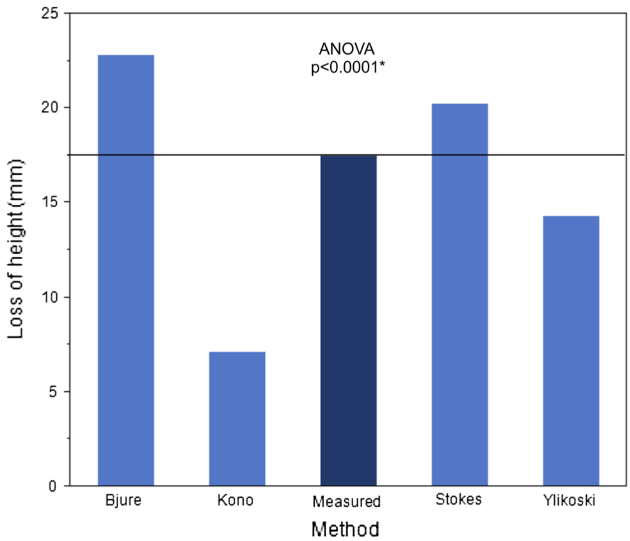

Fig. 2 Graph showing the mean loss of body height calculated using the methods of Bjure, Kono, Stokes and Ylikoski, and the mean measured loss of height. Analysis of variances (ANOVA) revealed significant difference between all the methods ($p < 0.0001^*$)

Table 2 Comparison in pairs for the methods of calculating the loss of body height

Methods compared	Mean difference (mm)	*p* value	Pearson's linear correlation coefficient (*r*)
Bjure vs. Kono	16	<0.0001*	0.96
Stokes vs. Kono	13	0.0002*	0.96
Kono vs. measured	10	0.0061*	0.92
Bjure vs. Ylikoski	8	0.0386*	0.97
Ylikoski vs. Kono	7	0.1224	0.96
Stokes vs. Ylikoski	6	0.2732	0.97
Bjure vs. measured	5	0.3853	0.94
Ylikoski vs. measured	3	0.8207	0.95
Stokes vs. measured	3	0.8872	0.94
Bjure vs. Stokes	3	0.91	0.99

* Statistically significant difference

groups of subjects, but results of analysis were superimposed on the whole population with idiopathic scoliosis.

Bjure et al. used standing antero-posterior radiographs of 62 patients with scoliosis; however, no information about type of scoliosis or curve magnitude was given. The logarithm of the trunk height loss associated with scoliosis was correlated with the Cobb angle of the primary curve [7]. The presented equation,

$$\mathrm{Log}Y = 0.011X + 0.177,$$

had an erroneous "+" sign [8]. In the next study 13 patients with severe curves (Cobb angles of more than 100°) were added to previous 62 and a corrected equation,

Table 3 Intraobserver reproducibility and interobserver reliability of the Cobb angle measurements and of calculating the loss of height associated with idiopathic scoliosis using the following methods: Bjure, Kono, Stokes, and Ylikoski

Method	Intraobserver reproducibility		Interobserver reliability	
	ICC	SEM	ICC	SEM
Cobb angle of the major curve	0.94	2°	0.95	2°
Bjure	0.98	1 mm	0.95	1 mm
Kono	0.97	2 mm	0.96	2 mm
Stokes	0.97	1 mm	0.96	2 mm
Ylikoski	0.98	1 mm	0.97	1 mm

ICC intraclass correlation coefficient, *SEM* median error for the single measurement

$$\mathrm{Log}Y = 0.011X - 0.177,$$

was presented [8].

Kono et al. [9] used radiological data of 140 patients (131 with IS and 9 with scoliosis associated with syndromes: Marfan, neurofibromatosis, syringomyelia, Down, arthrogryposis, Prader–Willi). The mean Cobb angle of the major curve was 51.8° (19°–112°). The equation,

$$Y = 0.6X + 2.6 \text{ mm},$$

developed by Kono et al. gave negative values of height loss in our group of patients with the major Cobb angle of 37° or less. These negative and illogical values were just a result of arithmetic formula. Kono et al. suggested that correction of body height was not necessarily required in the case of small Cobb angle; however, no particular limit of Cobb angle value was determined.

Ylikoski based his analysis on 130 girls with untreated IS [10]. No information about curve magnitude in this group was presented.

Stokes used dataset of radiological data of 387 patients with IS (182 with single curves and 205 with double curves) to analyze the relationship between the Cobb angles, spinal length and spinal height [11]. No information about curve magnitude of these subjects was given.

All four authors based their analysis on various groups of subjects, but only Kono et al. presented the exact Cobb angle values in the study group. This may suggest potential limitations of the methods in cases with particular Cobb angle values, but such limitations were specified by none of the authors.

There was no overall agreement between the loss of body height measured and calculated by use of the four presented methods. The difference between the measured and calculated loss of height by use of the methods of Bjure, Stokes and Ylikoski was not statistically significant. The insignificant differences in pairs, Bjure versus Stokes, and Stokes versus Ylikoski, partially stay in-line with

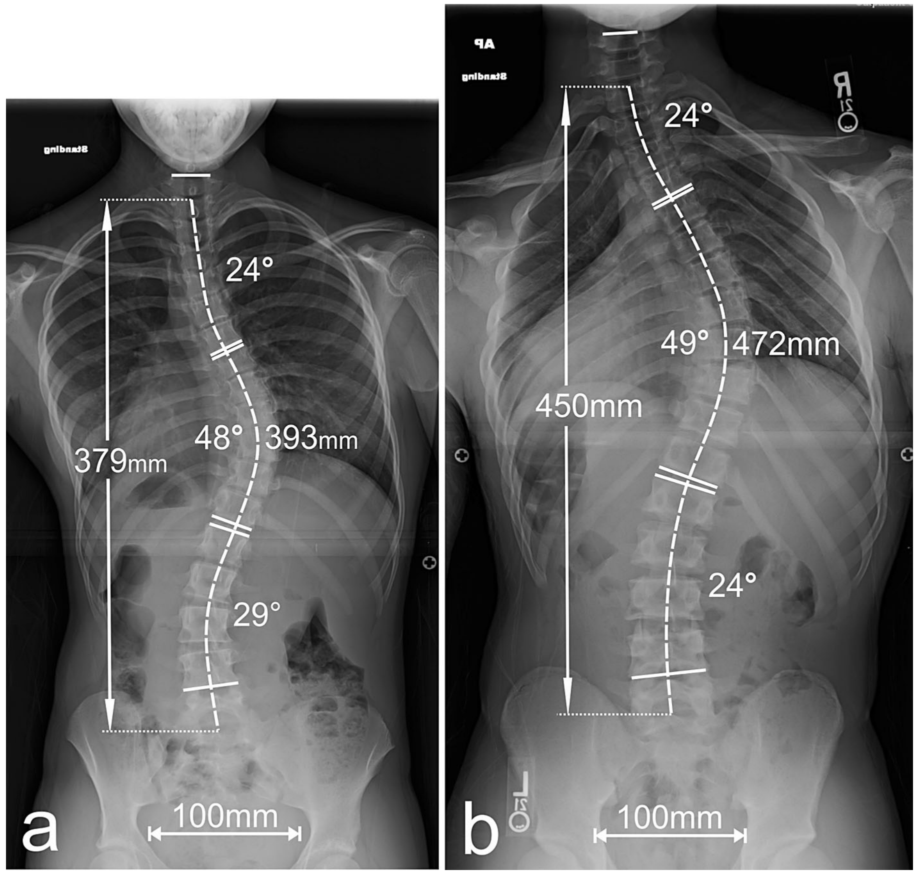

Fig. 3 Standing postero-anterior radiographs of 2 patients with similar Cobb angle values and different trunk height. **a** 10-year-old girl, T1–S1 spine length (*dashed line*) equals 393 mm and T1–S1 spine height (*arrows*) equals 379 mm. **b** 18-year-old boy, T1–S1 spine length (*dashed line*) equals 472 mm and T1–S1 spine height (*arrows*) equals 450 mm. The radiograph **a** is scaled-down proportionally

Stokes' study, who reported close agreement between his and Ylikoski's method and substantial difference between his and Bjure's analysis [11]. The other question is if the statistically significant differences are clinically significant. The accuracy of measurements of total body height performed by trained experts and by use of sophisticated rulers was reported to be ±1 mm which would make the differences between the methods revealed in our study clinically significant [17]. However, the diurnal and circadian variations in human body height may vary from 5 up to 19 mm, making the 16 mm difference (the highest revealed in our analysis) irrelevant [18–23]. When treating the patient with scoliosis the difference in total body height of 16 mm between 2 follow-ups may be clinically important for calculating peak growth velocity and timing of surgical intervention [24, 25]. Considering BMI or growth charts the significance of differences between the methods seem to be dependent on the actual patient's body height. The higher relative difference between the loss of height calculated using the four methods (relation of the loss of height to the actual height of the particular patient), the more likely clinical significance.

High correlation between the loss of height calculated using all the four methods and their high reproducibility and reliability similar to that for the Cobb angle measurements confirmed dependency of all the methods on the Cobb angle. High reproducibility and reliability as well as no need for additional parameters are undisputed advantages of all methods tested.

Comparison of the Patient #24 and the Patient #29 confirmed the hypothesis stated by Sarlak et al. that using the Cobb angle only for predicting the loss of body height associated with scoliosis may be inaccurate [12]. Two patients with similar curve pattern and Cobb angle values but with the difference in trunk height of 70 mm revealed to have similar loss of height due to their curves calculated by the four analyzed methods. The difference of the measured loss of body height between these patients was 8 mm and it could be more if the difference between their trunk heights was greater. This a priori inaccuracy of regression analysis model discourages from using these methods in clinical practice and opens space for a method considering both the curve angle and the trunk size.

Conclusions

Corrected total body height is an important clinical parameter in treating patients with IS. The radiographic methods of calculating the loss of body height due to scoliosis presented by Bjure et al., Kono et al., Stokes, and Ylikoski are commonly used in publications. Our study confirmed strong linear correlation between all the methods and their high reproducibility and reliability. However, no overall agreement for the loss of body height calculated using these methods was found. Analysis of two patients with similar Cobb angle, but with different trunk height, confirmed the hypothesis on potential source of inaccuracy in predicting the loss of body height due to scoliosis by use of all the methods tested. Results of our study suggest that a more individualized method for calculating the corrected body height in patients with IS may be developed.

Conflict of interest None.

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