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ORIGINAL ARTICLE

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Clinical photography in severe idiopathic scoliosis candidate for surgery: is it a useful tool to differentiate among Lenke patterns?

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Abstract

Purpose Clinical photography has proven to be reliable for posture assessment in adolescents and young adults with idiopathic scoliosis. This paper attempts to elucidate whether clinical photography is capable of distinguishing the distinctive characteristics in trunk deformity of the different Lenke patterns in patients with severe scoliosis candidate for surgery.

Methods One hundred and seventy-three patients (82% women), average age of 20.8 years and average largest curve magnitude of 58.7° were included. PA standing full-spine X-rays and digital photographs from the back of the trunk were measured.

Radiological measurements It is used to measure magnitude of the proximal thoracic (PTC), main thoracic (MTC) and thoracolumbar/lumbar (TL/LC) curves, T1 tilt and the clavicle–rib intersection angle.

Photographic measurements It is used to measure shoulder height angle, axilla height angle, waist height angle (WHA), right and left waist angles and trunk areas.

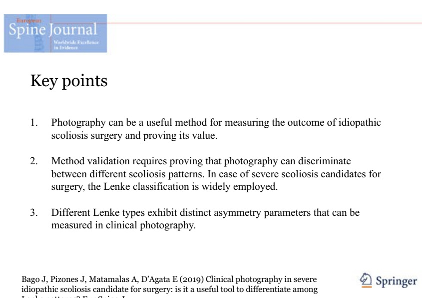
Statistical analysis One-way ANOVA to test mean differences among Lenke types for radiological and photographic measurements was performed. ROC curve analysis was conducted to find out cutoff values in photographic measurements to differentiate among curve patterns.

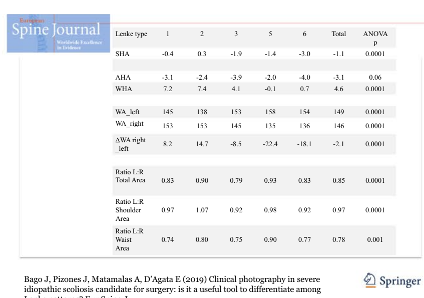
Results Most radiological and photographic measurements differ among curve patterns. On ROC curve analysis, solid cutoff values were found for WHA (AUC = 0.8), left waist angle (AUC = 0.81), right waist angle (AUC = 0.81) and the difference between left and right waist angles (AUC = 0.86) to differentiate between types 1 and 2 and the other three types (3, 5 and 6).

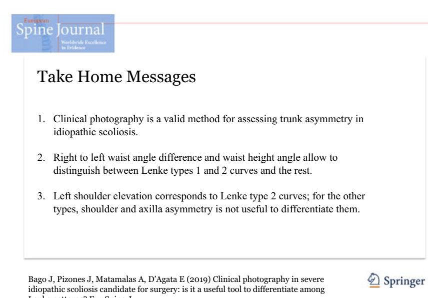
Conclusions Clinical photography is a valid method for assessing trunk asymmetry in severe idiopathic scoliosis. Specifically, for waist area measurements, robust cutoff values can be determined to discriminate among different curve patterns according to Lenke classification.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Idiopathic scoliosis · Physical examination · Clinical photography

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Introduction

Clinical photography has proven to be reliable for posture assessment in healthy adolescents [1] and adolescents and young adults with idiopathic scoliosis [2, 3]. Photography has been used to score trunk deformity in idiopathic scoliosis either by external observers [4, 5] or by the patient himself [6]. Matamalas et al. [7, 8] have defined the most reliable measurements in digital photography to assess shoulder and waist asymmetry in idiopathic scoliosis patients. The main purpose of their research was to find out which measurements with adequate inter- and intra-observer reliability were significantly related to the corresponding radiological measurements and had the best correlation with trunk deformity perception. The next step in testing the validity of these photographic measurements would be to test the hypothesis that it is possible to discriminate among different scoliosis patterns on the basis of certain cutoff values.

Lenke's classification [9] is usually employed to determine the curve pattern in severe idiopathic scoliosis, especially in those cases who are a candidate for surgery. It is an X-ray-based classification initially oriented to help in surgical planning to determine which curves should be included in the spine fusion, allowing selective fusion when appropriate. In addition, classification has shown satisfactory inter- and intra-observer reliability [10, 11].

The objective of this paper is to study a group of patients with severe idiopathic scoliosis scheduled for surgery, classify the patients according to Lenke's classification and to compare measurements on clinical photography between Lenke patterns in order to determine cutoff values able to discriminate between curve types.

Material and methods

This is a cross-sectional study of prospectively collected data from two registers of adolescents and young adults with idiopathic scoliosis scheduled for surgery. This research was approved by the IRB of the two participating centers. Only cases with a standing PA full-spine X-rays and a good-quality photograph were included. To limit confounding factors, only curves with typical patterns (i.e., left proximal thoracic, right main thoracic and left thoracolumbar/lumbar curves) were included.

Radiological measurements

On PA full-spine X-rays, the following measures were recorded: the magnitude of the proximal thoracic (PTC), main thoracic (MTC) and thoracolumbar/lumbar (TL/LC) curves. As a summary measure, the largest curve magnitude (LCM) was gathered. Furthermore, T1 tilt (T1 cephalic endplate tilt and horizontal angle) and the clavicle–rib intersection angle (CRIA), defined as the angle formed by the horizontal and a line joining the points where clavicles intersect rib cage [12], were measured.

Photographic measurements

Each patient underwent clinical photographs on the same day of the visit. Photographs were taken with a digital camera with a distance of 130 cm. Patients were told to adopt a relaxed standing position when the photographs were taken. For this study, only posterior (back) views were considered. At first, we marked the anatomic landmarks on the photographs which were further used to calculate our measures: C7 spinous process, the upper border of both acromion processes, the upper border of external axillary folds, the apex of the concavity of the waist and the tangent line to iliac crest prominence. These landmarks were marked on both the sides. Based on these reference landmarks, we calculated the following measures:

Shoulder height angle (SHA) (Fig. 1a)

It was defined as the angle formed between the line that joins the upper border of both acromion processes and the horizontal. The intra-class correlation coefficient (ICC) for intra-observer and inter-observer test–retest of 0.88 and 0.80 and standard error of measurement (SEM) of 0.99° has been published [7].

Axilla height angle (AHA) (Fig. 1a)

It was defined as the angle formed between the line that joins the upper border of both external axillary folds and the horizontal. ICC was 0.93 and 0.88; SEM was 0.83° [7].

Waist height angle (WHA) (Fig. 1a)

It was defined as the angle between a line drawn from the left to the right apex of waist crease and the horizontal line. ICC was 0.84 and 0.82; SEM was 1.33° [8].

Right and left waist angle (WA_right/WA_left) (Fig. 1a)

They were defined as the angle formed by the line of the lateral part of the chest wall and the tangent line to the iliac crest relief with the vertex at the concavity of the waist in both sides. The difference between right and left sides (ΔWAr_l) was calculated. Reliability (ICC) and SEM of WA right were 0.95°, 0.96° and 2.74°; these for WA_left were 0.93°, 0.92° and 2.56° [8].

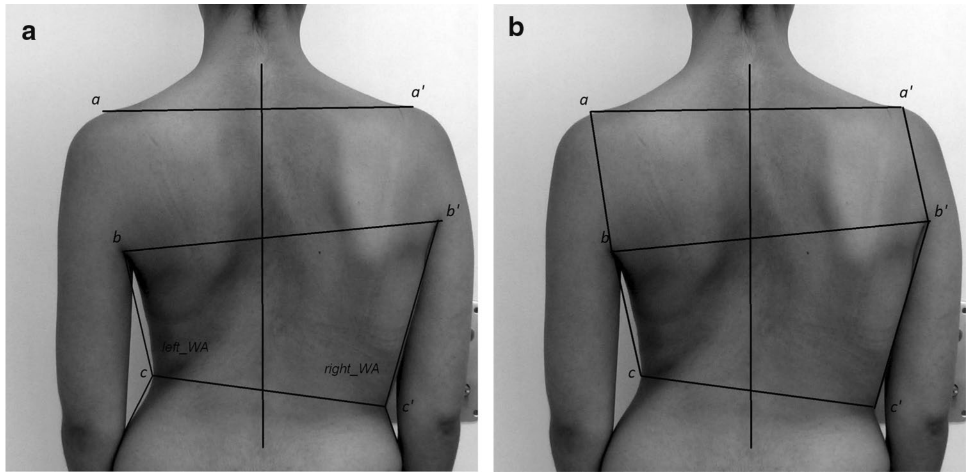

Fig. 1 **a** Reference points for shoulder (*a*, *a*′), axilla (*b*, *b*′) and waist (*c*, *c*′) measurements; left waist angle (left_WA) and right waist angle (right_WA). **b** Left and right trunk areas

Joining the acromion, axillary fold and waist apex points, a polygon was drawn; line C7-plumbline divides this polygon into two parts, right and left. Next, a line joining the two axillary folds was drawn which divides the polygon into two parts: one at the top (shoulder) and one at the bottom (waist). By doing this, we have four polygons from which the area can be measured (Fig. 1b). So, the ratio between the areas of the left and right half was determined (*Total_Area_ratio*); in addition, the ratio of the upper (*Shoulder_Area_ratio*) and lower (*Waist_Area_ratio*) polygons was also calculated. No reliability data for these measures were available.

The SurgimapSpine® (Nemaris Inc., New York, US) software was used for both the X-ray and clinical photography angular measurements, and Image J (National Institutes of Health, USA) was used for area measurements. Both the radiological and photographic measurements were assigned a positive or negative value according to the tilt direction. The right-hand thumb rule was used for this purpose: looking at the individual (or X-rays) from the back, a clockwise and anticlockwise tilt was considered positive and negative, respectively. For example, the tilt of T1 toward the right was assigned a positive value; elevation of the left shoulder was assigned a positive value, etc.

To classify the patients according to the Lenke classification, we used the established radiographic methodology using AP, lateral and bending X-rays; in addition, we calculated main thoracic/upper thoracic and main thoracic/thoracolumbar Cobb ratios and also considered T1 tilt and CRIA as adjunct to determine curve type which was finally decided under the agreement of two researchers (JB and JP).

Statistical analysis

Descriptive data were obtained for all radiological and photographic measures. To test the mean difference significance among the different curve types, a one-way ANOVA was conducted. Previously, homogeneity of variances for all variables was confirmed by Levene's test. Among the subtypes, differences were analyzed with ANOVA contrasts setting coefficients for individual variables or groups of variables and computing a *t* test [13]. Based on the information obtained from the preceding data, it was hypothesized that certain values of photographic measures could be established as threshold values to discriminate among Lenke types. To confirm this hypothesis, a ROC curve analysis was conducted and the area under the curve (AUC), sensitivity, specificity and Youden's index for each cutoff value were calculated. A rough guide generally accepted for classifying the accuracy of AUC is: 0.90–1 excellent; 0.80–0.90 good; 0.70–0.80 fair; 0.60–0.70 poor and 0.50–0.60 fail [14].

SPSS 25 (IBM Analytics, New York) software was used for calculations. Statistical significance was set at $p < 0.05$).

Results

One hundred and ninety-seven patients were eligible for the study. Twenty-four patients were rejected because of bad-quality photographies (14 cases), type 4 curves (6 cases) and atypical curves (4 cases). Finally, 173 cases (82% women), average age of 20.8 years, ranging from 11 to 42 years, and average largest curve magnitude (LCM) of 58.7° (range 40°–101°) were included. They were categorized according to the Lenke classification: type 1, 61 cases; type 2, 30 cases; type 3, 30 cases; type 5, 26 cases; and type 6, 26 cases. Type 4 curves were excluded due to small sample size.

Radiological measurements

Average radiological measures for the whole group and for each Lenke type are summarized in Table 1. Average T1 tilt for the whole sample was 0°: in 78 cases it was $-3°$ to $+3°$; in 46 cases it was $< -3°$ (tilt to the left); and in 49 cases it was $> 3°$ (tilt to the right). Average CRIA was $-1.75°$: in

Table 1 Average radiological measures for the whole sample and for each Lenke type

Lenke type	PTC (°)	MTC (°)	TL/L C (°)	T1_tilt (°)	CRIA (°)	Ratio MTC/PTC	Ratio MTC/TLC
1	29.1	−59.3	33.8	−1.0	−2.8	2.03	1.75
2	46.1	−61.7	32.7	+9.9	+1.1	1.33	1.88
3	22.1	−54.5	50.3	−3.0	−2.4	2.46	1.08
5	7.6	−32.6	52.6	−1.6	−0.5	4.28	0.62
6	17.4	−55.3	64.4	−3.7	−2.8	2.13	0.85
Total	25.9	−54.3	43.9	+0.05	−1.7		

PTC proximal thoracic curve, *MTC* main thoracic curve, *TL/L C* thoracolumbar/lumbar curve, *CRIA* clavicle–rib intersection angle

Table 2 Average photographic measures for the whole sample and for each Lenke type

Lenke type	1	2	3	5	6	Total	ANOVA *p*
SHA	−0.4	0.3	−1.9	−1.4	−3.0	−1.1	0.0001
AHA	−3.1	−2.4	−3.9	−2.0	−4.0	−3.1	0.06
WHA	7.2	7.4	4.1	−0.1	0.7	4.6	0.0001
WA_left	145	138	153	158	154	149	0.0001
WA_right	153	153	145	135	136	146	0.0001
ΔWA right_left	8.2	14.7	−8.5	−22.4	−18.1	−2.1	0.0001
Ratio L:R total area	0.83	0.90	0.79	0.93	0.83	0.85	0.0001
Ratio L:R shoulder area	0.97	1.07	0.92	0.98	0.92	0.97	0.0001
Ratio L:R waist area	0.74	0.80	0.75	0.90	0.77	0.78	0.001

SHA shoulder height angle, *AHA* axilla height angle, *WHA* waist height angle, *WA_left* left waist angle, *WA_right* right waist angle, *ΔWA right_left* right minus left waist angle difference

32 cases it was 0°; in 34 cases it was positive (indicating left shoulder elevation); and in 107 cases it was negative (indicating right shoulder elevation).

Photographic measurements

The average photographic measures for the whole group and for each Lenke type are summarized in Table 2.

Shoulder height angle (SHA)

ANOVA demonstrates a significant difference among the groups ($p = 0.0001$); type 2 was significantly different from the rest (*t* test = 0.004) in that it is the only type with the left shoulder elevated on average. When evaluating the validity of SHA to identify type 2 curves, an AUC of 0.68 was calculated indicating poor discriminative value.

Axilla height angle (AHA)

Differences among the groups were not statistically significant in ANOVA.

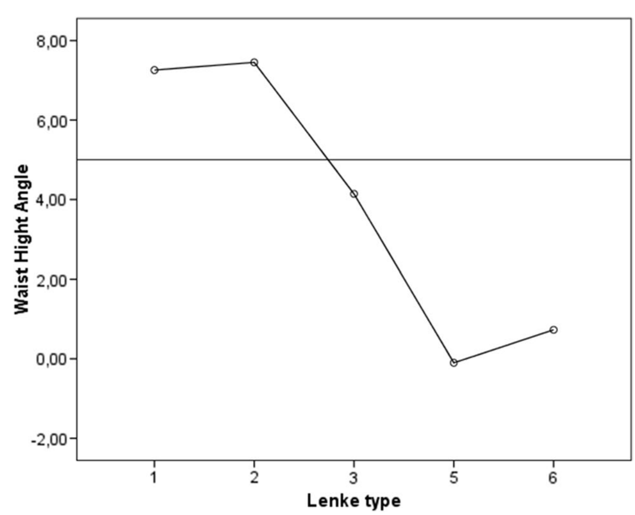

Fig. 2 Mean waist height angle (WHA) for each curve type

Waist height angle (WHA)

Differences among the groups were statistically significant (ANOVA, $p = 0.0001$). Types 1 and 2 showed a distinct WHA (*t* test, $p = 0.0001$) from the rest (Fig. 2). The discriminating ability of WHA to differentiate curves 1 and 2 from the rest was tested. An AUC of 0.805 (95% CI 0.738–0.871, $p = 0.0001$) was calculated; a threshold value of +5° has a sensitivity of 73.6%, a specificity of 75.6% and a Youden's index of 0.49 to identify curves type 1 or 2.

Left waist angle (WA_left)

One-way ANOVA showed significant differences among the groups ($p = 0.0001$). Types 1 and 2 are different from the rest. WA_left is valid to discriminate curve type with an AUC of 0.81 (95% CI 0.745–0.874, $p = 0.0001$); a threshold value of 150° has sensitivity 74.4%, specificity 72.5% and a Youden's index of 0.469.

Right waist angle (WA_right)

The differences were statistically significant among the groups (ANOVA, $p = 0.0001$) and types 1 and 2 differed from the rest (*t* test, $p = 0.0001$). The ability of WA_right to discriminate curve type was tested. AUC was 0.812 (95% CI 0.74–0.87, $p = 0.0001$); a threshold value of 150° has a sensibility of 64.8%, specificity of 80.5% and a Youden's index of 0.453.

Right-to-left waist angle difference (ΔWA r_l)

The differences were statistically significant among the groups (ANOVA, $p = 0.0001$). Contrasts analysis revealed that types 1 and 2 differed from the rest (*t* test, $p = 0.0001$) (Fig. 3a). Therefore, the discriminating ability of **ΔWA r_l** to differentiate between curves 1 and 2 from the rest was tested. Estimated AUC was 0.863 (95% CI 0.8–0.92, $p = 0.0001$); a threshold value of 0° had a sensibility of 73.6%, specificity of 82.9% and a Youden's index of 0.56 (Fig. 3b).

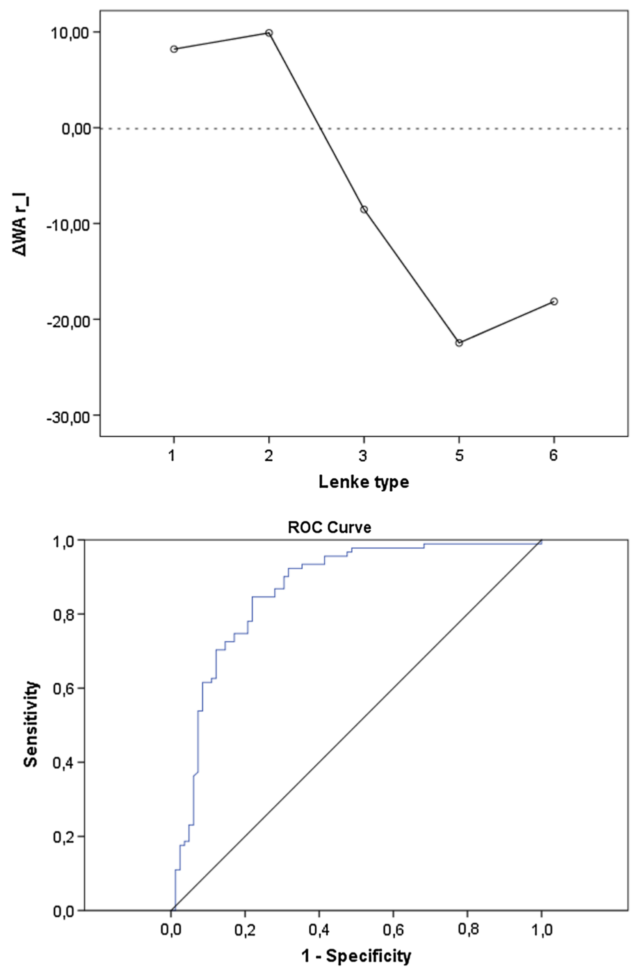

Fig. 3 **a** Mean right-to-left waist angle difference (ΔWA r_l) for each curve type. **b** ROC curve plotting sensitivity and 1-specificity for ΔWA r_l to differentiate curves type 1 and 2 from the rest

Total area ratio

The differences were statistically significant among the groups (ANOVA, $p = 0.0001$), and type 3 was significantly different from the rest (*t* test, $p = 0.001$). Nevertheless, ROC curve analysis showed this ratio is not valid to discriminate among the curve types (AUC 0.656).

Shoulder area ratio

The differences were statistically significant among the types (ANOVA, $p = 0.0001$); type 2 was significantly different from the rest (*t* test, $p = 0.0001$) as it is the only type with a ratio > 1, i.e., the left side is larger than the right. In ROC curve analysis, shoulder area ratio can discriminate between type 2 and the rest (AUC 0.784, CI 95% 0.69–0.87, $p = 0.0001$. Cutoff value of 1.00 has a sensibility of 70%, specificity of 71.3% and a Youden's index of 0.413.

Waist area ratio

The differences were statistically significant among the types (ANOVA, $p = 0.001$); type 5 was significantly different from the rest (*t* test, $p = 0.0001$) as it is the only type with a ratio < 0.85. This means that in type 5 the left-to-right asymmetry is smaller than in the other types. In ROC curve analysis, waist area ratio can discriminate between type 5 and the rest (AUC 0.77, CI 95% 0.67–0.87, $p = 0.0001$. A cutoff value of 0.85 has a sensibility of 65.4%, specificity of 82% and a Youden's index of 0.47.

Discussion

As trunk asymmetry negatively influences body image perception and quality of life in patients with idiopathic scoliosis, reducing this asymmetry should be a treatment goal. Consequently, a reliable method for assessing trunk asymmetry could be very useful in appraising treatment results. The clinical picture is a simple and inexpensive method of capturing trunk deformity associated with idiopathic scoliosis. Although with this tool the deformity is assessed only in two dimensions, it is eloquent enough to show the degree of asymmetry. Photography has proven to be a reliable method [3, 15]. Matamalas et al. [7, 8, 16] analyzed different proposed measures to determine which of them had better correlation with X-ray parameters and with body image perception. The objective of the present study was to obtain additional information on the external validity of photography measurements analyzing whether these measures could discriminate among different scoliosis patterns according to Lenke's classification.

Firstly, our strategy was based on comparing radiological parameter means among different curve types (Table 1). Type 2 is characterized by a large PTC, a positive (> 3°) T1 tilt and a small MTC/PTC ratio under 1.5, whereas in type 1 T1 tilt is, on average, close to 0° and the MTC/PTC ratio is over 1.5. Type 3 is characterized by an MTC/TLC ratio close to 1, whereas in type 6 the ratio is < 1. As expected, in type 5 MTC is smaller than in type 6 and MTC/TLC ratio is close to 0.5. We want to emphasize the possible usefulness of curve ratios in determining scoliosis patterns when not all required X-rays (side bendings and lateral views) are available [17–22].

Secondly, we analyzed the hypothesis that different Lenke types would present different trunk deformity parameters which could help the examiner to differentiate them using a back photograph. The results acceptably support this hypothesis. Shoulder height angle (SHA) differs significantly among Lenke groups. Type 2 is the only one that, on average, shows an elevated left shoulder. However, in the ROC curve analysis, no cutoff point was found to reliably differentiate among subtypes. No statistically significant difference was found among groups for axilla height angle (AHA). Waist height angle (WHA) is also different among Lenke types. Types 1 and 2 showed distinct WHA and an angle > + 5° (i.e., the left side is elevated) is a valid cutoff value to differentiate them from the other types with an 80.5% probability. Right and left waist angles and the difference between them (**ΔWA r_l**) appear as solid predictors of curve pattern. A left waist angle < 150° (this is a sharper, closer to 90° angle), a right waist angle > 150° (this is a flatter, closer to 180° angle) or a difference > 0° (right angle flatter than left angle) indicate that we are facing, with more than 80% probability, a type 1 or type 2 curve.

In addition to angular measurements, we also calculated the ratio between right and left areas. We presume left/right area ratio is a good estimate of the extent of asymmetry as in a state of perfect symmetry the ratio should be 1. The largest asymmetry is observed in types 1, 3 and 6. Nevertheless, a left-to-right ratio is not valid to differentiate among Lenke types. When analyzing separately the asymmetry of the upper part of the trunk (shoulder area ratio), type 2 is the only one with a ratio inversion and the left-hand side is larger than the right-hand one. This difference is statistically significant, and a shoulder area value > 1 differentiates between type 2 and the rest. On the other hand, the analysis of the lower part of the trunk (waist area ratio) indicates that type 5 had the smallest asymmetry; a cutoff ratio of 0.85 reliably differentiates between type 5 curves and the rest.

In summary, we can describe type 1 and type 2 curves as those with a waist height angle > + 5°, a left waist angle < 150°, a right waist angle > 150° and a right-to-left difference > 0° (right angle flatter than left angle). Type 2 differs from type 1 in that left shoulder is elevated and left shoulder area is larger than the right side. Obviously, types 3, 5 and 6 would show inverse characteristics to types 1 and 2; this is a waist height angle < + 5°, a left waist angle > 150°, a right waist angle < 150° and negative right-to-left difference. Types 3 and 6 are indistinguishable using proposed measurements, and type 5 is characterized by having a smaller asymmetry in the waist area (ratio > 0.85).

Our research confirms that the asymmetry of the upper part of the trunk, including the shoulders, is not specific to any curve type. As expected, type 2 showed an elevation of the left shoulder, but globally shoulder imbalance did not allow discriminating among different Lenke types. Our data confirmed the findings reported by other authors regarding the poor correlation between the upper thoracic curve magnitude and/or T1 tilt and clinical asymmetry measured in photographs [23, 24]. Moreover, the right shoulder elevation is a feature that does not predict the curve pattern. An extended perception is that an upright right shoulder corresponds to a main thoracic curve pattern. On the contrary, we found that the group with the greatest right shoulder overhang was type 6, i.e., a pattern with left lumbar curve predominance. It is also interesting to note the asymmetry at the axilla level. Axilla height angle (AHA) is not valid to discriminate among Lenke types. However, in types 1, 3 and 6, AHA is > 3° (this is the minimum detectable change reported for this measurement) [13] which indicates a right-side uprising. Consequently, in these curve types, reducing AHA to a value close to zero would be a treatment objective to restore trunk symmetry.

Parameters that best discriminate among curve types are those from the lower trunk area, i.e., from the waist. All the parameters (left waist angle, right waist angle, the difference between them and the waist height angle) can discriminate between type 1/type 2 curves and types 3, 5 and 6 with an AUC in ROC curve analysis > 0.80. This indicates that proposed cutoff values are solid enough to differentiate among curves. Waist asymmetry parameters were previously described by Qiu et al. [25]. However, they produce a cosmetic index composite which, in our opinion, was somewhat confusing. We decided to use angle raw values which proved to be reliable and valid. Finally, we assessed trunk asymmetry through trunk area measurements. This method was used by Sharma et al. [26] to analyze the effect of surgery on trunk asymmetry in a cohort of 33 idiopathic scoliosis patients. They found a significant reduction in trunk asymmetry after surgery, especially in the waist area. In our study, the area was delineated from the points used for the other measurements (i.e., shoulders, axilla and waist crease), which have already proven to be reliable enough; then, the area was divided in half using the C7-vertical line. We were faced with the problem that many photographs could not be calibrated, and therefore, we could not calculate the surface as a metric unit. The area was then measured in dot per inches, and the left/right ratio was used as an asymmetry index. In order to speed up the procedure, it would be very valuable to have a semiautomatic measurement system that calculates the asymmetry indices using reference points.

There are some limitations to this research. Firstly, the sample size ($n = 173$) is large, but 35% of the cases are type 1 and no type 4 (triple curve) cases were included. Secondly, in order to improve sample homogeneity and eliminate confounding factors, only patients with the right thoracic curve and left lumbar curve patterns were included. Therefore, the observed results should only be applied to these types of curves. It is likely that the inverse pattern (especially the right lumbar curves) showed similar findings but with the opposite sign. Nevertheless, this would require confirmation. Thirdly, the study sample consisted of two cohorts from two centers, and clinical pictures are part of the preoperative evaluation. Consequently, only patients with severe deformities were included which explains why average curve magnitude is greater than 40°. Therefore, the conclusions of the study would only be applicable to patients with these characteristics as it is possible that the findings are not generalizable to low degree scoliosis.

This paper represents a new step in the validation process of clinical photography as a method of evaluating trunk deformity in idiopathic scoliosis. Trunk asymmetry has also been evaluated with surface topography (ST) techniques. The most recent information proves that it is a reliable and valid technique due to its good relationship with the radiological parameters of scoliosis that has been found [27, 28]. However, the ultimate goal of ST is to allow scoliosis monitoring in order to reduce the number of X-rays. With the available data, we do not believe that clinical photography was valid and reliable enough to monitor scoliosis progression. We focus our attention on evaluating trunk asymmetry with a procedure that has the advantage over ST of being highly available and inexpensive. The next step should be the responsiveness analysis after surgical treatment and the effect size estimation. Our hypothesis would be that clinical photography is a method to demonstrate the clinical efficacy and value of surgical treatment in the management of idiopathic scoliosis. Although outside the objectives of this study, it is worth noting that the usefulness of clinical photography in the evaluation of pediatric scoliosis relies on the fact that X-rays have been associated with the risk of developing cancer [29].

Conclusion

Our data confirm that clinical photography is a valid method for assessing trunk asymmetry in idiopathic scoliosis. Specifically, for waist area measurements, robust cutoff values can be determined to discriminate among different curve patterns according to Lenke classification.

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Compliance with ethical standards

Conflict of interest The authors of this paper have no conflict of interest.

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