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Relationship between Clinical Contourometric Measurements and Vertebral Rotation in Adolescent Idiopathic Scoliosis

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A B S T R A C T

The relationship between trunk and spine deformity has yet not been well defined. The purpose of this study was to identify the relationship between clinical (contourometric) and radiographic methods of scoliotic deformity evaluation. Our second objective was to create mathematical formulas for calculating radiographic parameters based on defined correlations of multiple parameters. We did a study of 136 preoperatively analysed patients with idiopathic scoliosis. Altogether, 189 lateral curvatures were assessed. Based on Lenke's classification, curves were divided into three groups: a thoracic, a thoracolumbar and a lumbar curve group. Each group was analyzed separately to determine relationships between clinical contourometric (scoliometer value, humpometer values) and radiographic measurement (apical vertebral rotation (AVR) according to Drerup). On the grounds of statistically significant correlation coefficients of most clinical parameters and Drerup rotation we found good relationships between trunk and spine deformity. Using the best correlated clinical parameters and multiple regression statistical analysis we created mathematical formulas for prediction of scoliotic AVR in higher degree curves.

Key words: *vertebral rotation, scoliosis, topography, scoliometer, humpometer*

Introduction

Experts involved in diagnosing and treating scoliosis need to evaluate the degree of deformity. The degree of deformity together with some other parameters further defines different treatment options. There are many different methods used for scoliosis evaluation. Some of these methods are based on measurements from plain radiographs. Others use clinical back contour measurement to define different aspects of trunk shape. Since the first introduction, radiology became the primary method to diagnose and further record and document scoliosis progression. Apical vertebral rotation (AVR) is an important aspect of a scoliotic three-dimensional deformity[1]. Recent studies show axial rotation in combination with other parameters to be useful in evaluation of the progression pattern of idiopathic scoliosis[2]. There are many original methods proposed for the measurement of AVR[3–7] In this study we used Drerup's modification of the Nash-Moe method to radiographically evaluate AVR. In order to evaluate scoliotic curve progression, periodic monitoring is required. A full radiographic examination each time leads to undesirably high X-ray exposure so that a non-invasive alternative for the assessment of scoliosis is highly desirable[8–10]. Monitoring usually combines clinical examination and measurement of the Cobb angle from standing scoliosis radiographs. Many studies have attempted to evaluate scoliotic deformity using methods of evaluating back shape[11–24]. The foundations of such studies were the originally constructed measuring devices for evaluating different aspects of trunk shape. Most studies investigated the relationships between radiographically

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measured spine deformity, and different clinically measured aspects of trunk shape[8,11–14,18–28]. Some authors deny any correlation between trunk (contourometric scoliometer and humpometer measurements) and spine (radiographically assessed vertebral rotation and Cobb angle) deformity or find it statistically insignificant[11–13,18]. Other studies find a statistically significant correlation between trunk and spine deformity, which provided several mathematical formulas for coronal deformity degree prediction (Cobb angle) based on scoliometer value[25,28]. On the other hand, to the authors' best knowledge, formulas for prediction of vertebral rotation using scoliometer and humpometer measurements are not being published. The purpose of the current study was to assess different aspects of trunk deformity using the simplest possible measurement techniques (scoliometer and humpometer) and to investigate their relation to radiographically measured vertebral rotation. Mathematical formulas based on the correlation between the parameters in highest correspondence were created with the desire to eventually reduce unnecessary X-ray exposure during monitoring of scoliosis progression.

Materials and Methods

From February 2002 until October 2007 in our hospital we evaluated each of 164 scoliotic children and adolescents two days preoperatively. Of these, only 136 patients who met the criteria of having a diagnosis of juvenile or adolescent idiopathic scoliosis were included in the study. All other diagnoses and etiologies of scoliosis were excluded. There were 120 female and 16 male patients. The median age was 15 years, with upper and lower quartiles ranging from 14 to 17 years. The median height was 164.8 mm with upper and lower quartiles spanning from 159 mm to 169.5 mm. The median weight was 51.2 kg with upper and lower quartiles at 46 and 56.3 kg. Altogether 189 curves were analysed. In all patients we performed a clinical assessment measuring scoliometer and humpometer values as well as radiographic measurement of vertebral rotation. Scoliometer and humpometer measurements were done in a forward bending position, standing with their feet together, their knees straight and arms held out towards the floor with hands together as described by Bunell[15]. The examiner obtained scoliometer and humpometer measurements placing instruments gently along the spine perpendicular to the long axis of the body. Several measurements at different levels were made, and the largest degree of the deformity to either side was recorded. If double curves were noticed scoliometer and humpometer measurements were noticed at two different levels. We used the scoliometer device described by Pruijs[29]. The scoliometer was originally described as a screening device that measures the angle of trunk rotation[15]. For contourometric measurements we also used a humpometer device similar to the one described by Thulbourne and Gillespie[13]. These authors described several parameters measured using the humpometer. For all patients we measured hump height (H), rib

Fig. 1. Parameters obtained using humpometer device similar to one used by Gillespie, H – hump height, D – rib depression, W – distance of hump from midline.

depression (D), deformity height (C=H+D), distance of hump from midline (W), hump gradient (H/W) and depression gradient (D/W) (Figure 1). Using humpometer measurements we also calculated the rotation index (I=C/2W) described by Götze[11,12].

For radiographic measurement of vertebral rotation we used Drerup's modification of the Nash-Moe method. The method is based on pedicle shadow migration in relation to the underlying vertebral body. Measurements were performed on the apical curve vertebrae. According to Drerup's modification of the Nash-Moe measurement scale[6] only curves with an AVR ≤40° were statistically analysed, leaving us with 177 curves. Therefore, based on Lenke's classification, there were 111 curves in group I (thoracic curves), 19 in group II (thoracolumbar curves), and 47 in group III (lumbar curves). Results were analysed using nonparametric statistics. Relationships between parameters were analysed using the Spearman correlation test. Based on defined correlations using multiple regression analysis we created mathematical formulas for prediction of AVR according to Drerup.

Results

Each group was analysed separately to determine whether there is any relationship between spine (radiographic measurement) and trunk (clinical measurement) deformity. Using the nonparametric Spearman correlation test we analysed relationships between AVR according to Drerup and scoliometer angle of trunk rotation (S), humpometer measured hump height (H), humpometer measured rib depression (D), calculated deformity height (C=H+D), hump gradient (H/W), depression gradient (D/W) and Götze rotation index (I=C/2W).

Group I – Thoracic curve's

R and p-values are presented in Table 1. Based on the correlations defined in Table 1 and using multiple regression, we were able to construct a mathematical formula for predicting the AVR according to Drerup (CVR – calculated apical vertebral rotation) in thoracic curves.

$$CVR=8.737+0.671\times S+2.159\times H$$

Statistically significant betas for the combination of scoliometer value (S) and humpometer hump height (H) were beta(S)=0.487 and beta(H)=0.242. The standard error of estimate=6.697°.

TABLE 1
RELATIONSHIP BETWEEN APICAL VERTEBRAL ROTATION ACCORDING TO DRERUP AND CONTOUROMETRIC PARAMETERS IN THE THORACIC CURVE GROUP

Relationship between parameters	R-values	p-values
AVR and S	0.648886	0.000000
AVR and H	0.591502	0.000000
AVR and D	0.338554	0.000279
AVR and C	0.567002	0.000000
AVR and H/W	0.591085	0.000000
AVR and D/W	0.335423	0.000320
AVR and I	0.568132	0.000000

AVR – apical vertebral rotation according to Drerup, S – scoliometer angle of trunk rotation value, H – humpometer measured hump height, D – humpometer measured rib depression, C – calculated deformity height (C=H+D), H/W – hump gradient, D/W – depression gradient, I – Götze rotation index (I=C/2W)

Using the above formula we calculated the CVR for all thoracic curves. Median CVR was 23° with lower and upper quartiles at 18° and 28° respectively (Figure 2).

For all thoracic curves we calculated the difference between the measured AVR and the calculated CVR. Median difference between AVR and CVR was 5° with lower and upper quartiles at 2° and 8° respectively (Figure 3).

Group II – Thoracolumbar curve's

R and p-values are presented in Table 2. Based on the correlations defined in Table 2 and using multiple regression, we were able to construct a mathematical formula for the CVR in thoracolumbar curves.

$$CVR=16.078+0.986\times S$$

Statistically significant beta for scoliometer value (S) was beta(S)=0.586 and the standard error of estimate =8.337°.

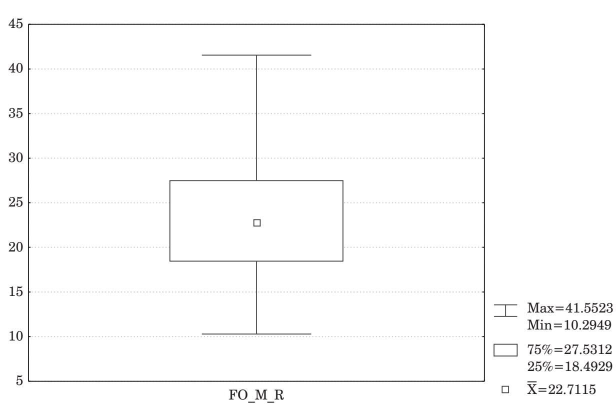

Fig. 2. Distribution of calculated apical vertebral rotations (CVR) according to Drerup obtained using predictive formula in thoracic curve group.

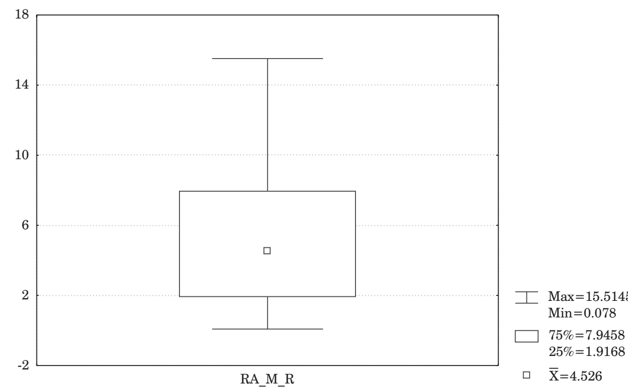

Fig. 3. Distribution of differences between measured apical vertebral rotations (AVR) and calculated apical vertebral rotations (CVR) in thoracic curve group.

TABLE 2
RELATIONSHIP BETWEEN APICAL VERTEBRAL ROTATION ACCORDING TO DRERUP AND CONTOUROMETRIC PARAMETERS IN THE THORACOLUBAR CURVE GROUP

Relationship between parameters	R-values	p-values
AVR and S	0.659999	0.002105
AVR and H	0.548121	0.015111
AVR and D	0.195085	0.423502
AVR and C	0.417509	0.075307
AVR and H/W	0.517112	0.023373
AVR and D/W	0.162482	0.506306
AVR and I	0.451164	0.052521

AVR – apical vertebral rotation according to Drerup, S – scoliometer angle of trunk rotation value, H – humpometer measured hump height, D – humpometer measured rib depression, C – calculated deformity height (C=H+D), H/W – hump gradient, D/W – depression gradient, I – Götze rotation index (I=C/2W)

Using the above formula we calculated the CVR for all thoracolumbar curves. Median CVR was 24° with lower and upper quartiles at 21° and 28° respectively (Figure 4).

For all thoracolumbar curves we calculated the difference between the measured AVR and the calculated CVR. Median difference between AVR and CVR was 3° with lower and upper quartiles at 1° and 11° respectively (Figure 5).

Group III – Lumbar curve's

R and p-values are presented in Table 3. According to the correlations defined in Table 3 and using multiple regression, we again constructed a mathematical formula for the CVR in lumbar curves.

$$CVR=4.102+1.109\times S+6.031\times H$$

Statistically significant betas for the combination of scoliometer value (S) and humpometer hump height value (H) were beta(S)=0.474 and beta(H)=0.346. The standard error of estimate=8.374°.

TABLE 3
RELATIONSHIP BETWEEN APICAL VERTEBRAL ROTATION ACCORDING TO DRERUP AND CONTOUROMETRIC PARAMETERS IN THE LUBAR CURVE GROUP

Relationship between parameters	R-values	p-values
AVR and S	0.569069	0.000030
AVR and H	0.672988	0.000000
AVR and D	0.013903	0.926102
AVR and C	0.516597	0.000201
AVR and H/W	0.617903	0.000004
AVR and D/W	–0.051528	0.730865
AVR and I	0.369976	0.010477

AVR – apical vertebral rotation according to Drerup, S – scoliometer angle of trunk rotation value, H – humpometer measured hump height, D – humpometer measured rib depression, C – calculated deformity height (C=H+D), H/W – hump gradient, D/W – depression gradient, I – Götze rotation index (I=C/2W)

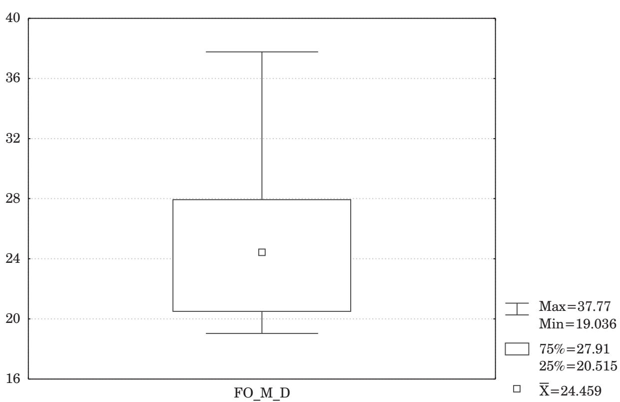

Fig 4. Distribution of calculated apical vertebral rotations (CVR) according to Drerup obtained using predictive formula in thoracolumbar curve group.

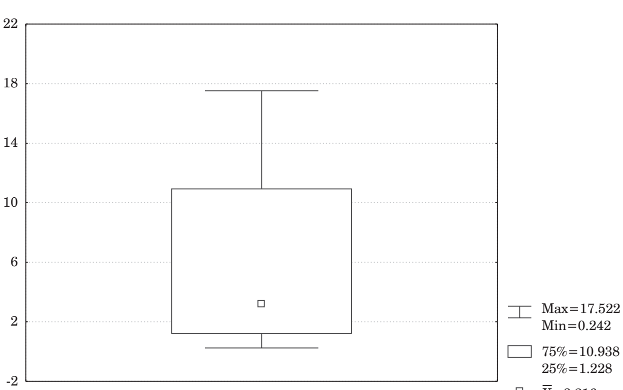

Fig 5. Distribution of differences between measured apical vertebral rotations (AVR) and calculated apical vertebral rotations (CVR) in thoracolumbar curve group.

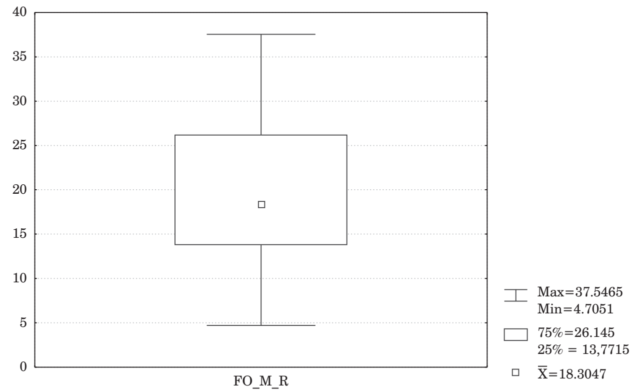

Fig 6. Distribution of calculated apical vertebral rotations (CVR) according to Drerup obtained using predictive formula in lumbar curve group.

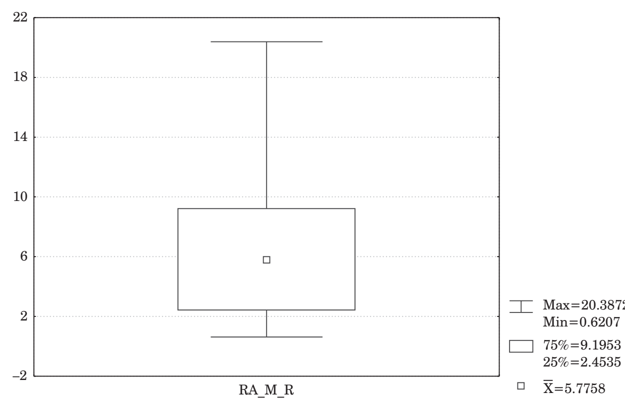

Fig 7. Distribution of differences between measured apical vertebral rotations (AVR) and calculated apical vertebral rotations (CVR) in lumbar curve group.

Using the aforementioned formula we calculated the CVR for all lumbar curves. Median CVR was 18° with lower and upper quartiles at 14° and 26° respectively (Figure 6).

For all lumbar curves we calculated the difference between the measured AVR and the calculated CVR. Median difference between AVR and CVR was 6° with lower and upper quartiles 2° and 9° respectively (Figure 7).

Discussion

Scoliosis is a three-dimensional deformity of the spine. Unfortunately, the scoliotic deformity is dynamic, and has a tendency to progress significantly during a short period of time. Progression is not linear but is related to the intervals of rapid growth especially during the adolescent period. Therefore, periodic monitoring combining clinical examination and measurements from standing scoliosis radiographs is mandatory. In order to evaluate spine deformity it is necessary to obtain measurements from posteroanterior radiographs of the spine. Radiographically measured vertebral rotation is an important parameter for scoliosis evaluation and curve progression prognosis[1,2]. Monitoring by full radiographic assessment during the period of rapid growth is often necessary every 3–6 months[8]. According to some studies there is an increased risk of carcinogenesis due to lifetime radiation exposure in AIS patients[30–36]. Some authors suggest modifications of radiographic methods in order to decrease carcinogenesis risk[31,37,38], thus a non-invasive alternative for the assessment of scoliosis is still highly desirable[8,10].

Before the availability of radiography, Adams used plaster casts of the back surface as the primary method for recording the deformity and demonstrating effects of treatment[18]. Later many studies have attempted to evaluate scoliotic deformities using methods of evaluating back shape[8,11–24,26,27,39–43]. These studies were based on new instruments for evaluating different aspects of trunk shape. Some authors measured angle of trunk rotation[15,29], others measured rib hump[11,13,14], and some used optical instruments[16,17,21–24,26,27,40–43] to evaluate trunk asymmetry. Using clinical contourometric measurement methods of recording back shape we assess trunk and not spine deformity. Therefore it is important to investigate any relationships between radiographic and contourometric parameters. In our research we investigated the relationship between radiographically measured AVR and contourometrically measured back shape parameters obtained by scoliometer and humpometer.

Throughout history many authors have evaluated vertebral rotation[14,17,44–48]. Most studies used standard standing posteroanterior radiograph of the spine, from which vertebral rotation was measured using some of described measurement techniques. In one study group of authors investigate intraobserver reproducibility and interobserver reliability of the radiographic parameters in spinal deformity evaluation. These authors report excellent results obtained measuring parameters from posteroanterior radiographs but less reproducible and reliable measurements from the lateral radiographs[49]. In our study we also measured vertebral rotation from standard standing posteroanterior radiograph of the spine.

There are lots of original methods presented for AVR measurement. Cobb described his method based on the position of the tip of the spinous process in relation to the underlying vertebral body[3]. Others found that the tip of the spinous process is too difficult to visualize and suggested using pedicle shadows instead. In 1969 Nash and Moe presented simple method of vertebral rotation measurement using pedicle shadows[4]. Some authors propose other methods of vertebral rotation measurement and report some disadvantages of the Nash-Moe measurement method at larger degrees of vertebral rotation[5]. Other authors advocate modifications of existing methods. Drerup suggests a modification of the Nash-Moe measurement scale and suggests using it only until 40° degrees of rotation[6]. Perdriolle presents a method of vertebral rotation measurement from plain radiographs using a torsion meter[1,48]. Different authors used torsion meters for AVR measurement in their studies[1,14,25,44–48]. Perdriolle's method measures rotation according to the position of the pedicle shadow in relation to the same vertebral body's borders' shadow. Some studies compare manual and digital measurements of radiographic parameters in patients with adolescent idiopathic scoliosis[50]. There are also many studies that use methods of AVR measurement from CT and MR scans[47,51–57]. In this study we used the modification of the Nash-Moe method according to Drerup to radiographically evaluate AVR[6]. According to the suggestions of Mehta and Drerup[5,6] in the current study only curves with AVR ≤ 40° were statistical analysed.

Most studies concerning external back shape measurement techniques investigated relationship between radiographically measured spine deformity, and different clinically measured aspects of trunk shape[8,11–14,18–28]. Some authors deny any correlation between trunk (contourometric scoliometer and humpometer measurements) and spine (radiographically assessed vertebral rotation and Cobb angle) deformity or find it statistically insignificant[11–13,18]. On the other hand, some studies find statistically significant correlations between some trunk and spine deformity parameters, and on these grounds provide mathematical formulas for coronal deformity degree prediction (Cobb angle) based on scoliometer value[25,28]. In our study we assessed different aspects of trunk deformity using the simplest possible techniques (scoliometer and humpometer) and investigated their relation to radiographically measured vertebral rotation.

The scoliometer was one of the instruments designed to assess angle of trunk rotation (ATR). The precursor of today's scoliometers was Schulthess's meter, called »Nivelliertrapez« dating back in 1902. Later Bunnell and Pruijs[15,29] presented scoliometers that also measured ATR – the angle between the horizontal plane and the plane across the posterior part of the trunk at the point of maximum deformity at each side. Different authors use Pruijs' scoliometer for trunk asymmetry quantification by measuring angle of trunk rotation[29,58]. In this study we measured ATR using Pruijs' scoliometer[29] in a forward bending position, standing with feet together, knees straight and arms towards the floor with hands together as described by Bunell[12].

There are few studies that analyse relationships between radiographic measurements and measurements obtained using a humpometer.

In the research done by Götze[11,12] rotation index in idiopathic scoliosis has been defined as a parameter calculated using humpometer measurements. Götze found rotation index to bee independent of the angle of deformity measured radiographically. Later, in a study by Heise[19], good overall correlation between surface deformity (Götze rotation index) and Cobb angle was shown, however, single measurements varied too widely to make surface documentation a real alternative to x-ray films. In our study there was a statistically significant correlation between apical vertebral rotation and Götze rotation index in thoracic and lumbar curve groups, but in the thoracolumbar curve group a correlation existed, but it did not reach statistical significance. Like some other authors[19] we consider the Götze rotation index to be suitable only for documenting the cosmetic appearance of scoliosis. Moreover other analysed contourometric parameters showed closer relationships with apical vertebral rotation and therefore the Götze index has not been used in formulas for Drerup AVR prediction.

Another study using a humpometer device analysed the relationships between hump height (H), rib depression (D), calculated deformity height (C=H+D), hump gradient (H/W) and depression gradient (D/W) with degree of lateral curvature (Cobb angle) and the Nash-Moe AVR. The authors report a lack of any correlation and no clear linear relationship was found[13]. In our study we used a humpometer device similar to the one used by Thoulbourne and Gillespie and have shown statistically significant correlations of all humpometer parameters with the Drerup AVR in the thoracic curve group. We emphasize a lower degree of correlation for rib depression (D) and depression gradient (D/W). The thoracolumbar and lumbar curve groups showed statistically significant correlations for hump height (H), calculated deformity height (C=H+D) and hump gradient (H/W). In the thoracolumbar curve group, rib depression (D) and depression gradient (D/W) did not reach statistically significant correlation, and in lumbar curve group these parameters showed no correlation or a negative correlation. The obtained correlations enabled us to use hump height in formulas for Drerup AVR prediction in the thoracic and lumbar curve groups.

Other authors also use a measuring device similar to Gillespie's humpometer, and show statistically significant correlations between humpometer measured trunk asymmetry and radiographically measured Cobb angle and Perdriolle AVR[14]. The results of our research also show statistically significant correlations of some humpometer measured parameters with Drerup AVR in all three groups.

Some authors using optical topographic measurements (Moiré photography and raster-stereophotography) showed positive correlations of the surface asymmetry with both Cobb angle and vertebral rotation, however the correlation of surface asymmetry and vertebral rotation did not reach statistical significance[18]. This study using other contourometric measuring devices showed statistically significant correlation between trunk asymmetry and Drerup AVR.

Korovessis et al.[25] conducted a study in order to create mathematical formulas for Cobb angle prediction based on trunk rotation scoliometer measurements. They report a statistically significant correlation between Cobb angle and scoliometer measurements in the thoracic and lumbar curve groups. In the lumbar curve group the authors showed a significant correlation between scoliometer value and Perdriolle vertebral rotation. They presented two formulas for Cobb angle prediction – one for thoracic and other for lumbar curves[25]. Korovessis et al.[25] suggest using a scoliometer together with their formulas in screening for scoliosis in schools. In our study, all three groups showed statistically significant correlation of scoliometer value and Drerup AVR. Instead of formulas for Cobb angle prediction we constructed formulas for Drerup AVR prediction also using a scoliometer, but in combination with humpometer measurements.

Sapkas et al.[28] also analysed the relationships between scoliometer value and Cobb angle, Nash-Moe vertebral rotation, and Risser's sign. They reported statistically significant correlations in all but the lumbar group. In their statistical analysis the authors used a multiple regression analysis[25,28]. Our study showed statistically significant correlation between Drerup AVR and scoliometer value in all three groups allowing mathematical formulation. Multiple regression analysis was also performed.

Conclusion

Radiographic evaluation of scoliotic spines is a well established and exact method. Apical vertebral rotation is an important aspect of scoliotic deformity especially in terms of progression prognosis[1,2]. In long-term follow-up these patients acquire a remarkable radiation exposure. Measurement of additional clinical parameters has intended to minimize this exposure. Documentation of surface deformities follows the presumption of correlation between these and radiographic parameters. In this study we showed statistically significant relationships between scoliometer and humpometer measured surface deformity and radiographically measured Drerup AVR. Using the parameters in highest correlation we present formulas for predicting the Drerup apical vertebral rotation in higher degree curves[59].

Formulas:

1. Thoracic group $CVR=8.737+0.671\times S+2.159\times H$
2. Thoracolumbar group $CVR=16.078+0.986\times S$
3. Lumbar group $CVR=4.102+1.109\times S+6.031\times H$

Simple back shape measurement methods (scoliometer and humpometer) in combination with the proposed formulas allow us to predict apical vertebral rotation. These formulas are not recommended to be used as a screening tool because all the curves analysed were preoperative higher degree curves. Therefore the proposed formulas used in combination with surface measurements, despite significant correlations, still do not present a real alternative to x-rays.

R E F E R E N C E S

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POVEZANOST KLINIČKIH KONTUROMETRIJSKIH MJERENJA I ROTACIJE KRALJEŠKA KOD ADOLESCENTNIH IDIOPATSKIH SKOLIOZA

S A Ž E T A K

Do danas još uvijek nije do kraja definiran odnos između deformacije trupa i podležeće deformacije kralješnice. Cilj ovog istraživanja bio je ispitati povezanost između kliničkih (konturometrijskih) i radioloških metoda evaluacije skoliotične deformacije. Nadalje cilj je bio temeljem definiranih korelacija primjenom više parametara načiniti algoritme za izračunavanje radioloških parametara. Istraživanjem je obuhvaćeno 136 preoperativno analiziranih ispitanika kod kojih je evaluirano 189 krivina. Krivine su prema Lenke-ovoj klasifikaciji podijeljene u tri grupe (grupa torakalnih, torakolumbalnih i lumbalnih krivina). Svaka grupa analizirana je zasebno kako bi se utvrdila povezanost između kliničkih konturometrijskih (skoliometarski i gibometarski mjerenih parametara) i radioloških mjerenja (rotacije apikalnog kralješka po Drerupu). Na temelju statistički značajnih koeficijenata korelacije većine konturometrijskih parametara i radiološki mjerene Drerupove apikalne rotacije kralješka zaključujemo da postoji dobra povezanost između deformacije trupa i deformacije kralješnice. Temeljem dokazanih korelacija primjenom multiple regresije koncipirali smo formule kojima pomoću najbolje povezanih konturometrijskih parametara možemo izračunati Drerup-ovu rotaciju apikalnog kralješka kod većih krivina.