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Comparison of Spatial Photogrammetry and Digital Radiology in the Diagnosis of Spinal Curvature

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Abstract

Proper diagnosis is a basis in the treatment of scoliotic posture and scoliosis. The aim of the study was to compare Moiré's spatial photogrammetry and Exhibeon digital radiology in the assessment of the primary curvature of the spine. The study involved 28 girls aged 7-18 years with scoliotic posture and scoliosis. Body posture as well as the spine were examined using Moiré's spatial photogrammetry and the Exhibeon digital radiography method. Multiple regression analysis showed a significant but low correlation between the angle of primary curvature determined by the Moiré method and one determined using the X-ray method. Screening analysis of variance showed significant relationships between the primary spinal curvature determined by X-ray with the age of the subjects. The Cobb angle increased with the age of subjects. There was no such relationship between the primary curvature angle of the spine determined by the Moiré method and the age of the subjects. The obtained results indicate a moderate convergence of the primary spinal curvature variables assessed using the Moiré spatial photogrammetry method and Exhibeon digital radiography. X-ray examination is considered to be more reliable and credible. The examination of body posture and spine using Moiré's spatial photogrammetry should play a screening and complementary role.

Keywords: primary spinal curvature, Moiré method, Exhibeon digital radiology method

1. Introduction

The search for reliable, repeatable and non-invasive ways to assess the structure and shape of the spine has led to the use of spatial photogrammetry and digital radiology (Dunn et al. 2018; Cho et al. 2018). Correct diagnosis is the basis in the treatment of scoliosis. In testing, apart from acquainting oneself with the symptoms, we try to determine the cause of these disorders (Mahaudens et al. 2018; Ng et al. 2017). This is extremely difficult, and thus, we try to reproduce their pathogenesis on the basis of clinical symptoms and subjective examination (Gerdhem, 2018; Furlanetto et al. 2016). Such a manner of procedure allows causal therapeutic treatment (Stasikelis & Carpenter, 2018; Jada et al. 2017). The diagnosis of scoliosis requires a minimum 10° Cobb angle (Kumar et al. 2017). For scoliosis, it is important to recognize the primary and secondary deflection and its progression (De la Garza Ramos et al. 2017; Simon et al. 2018). Prognosis in scoliosis is based on observation and analysis of the natural history of the disease (Ilharreborde, 2018; Jin, 2018). If the curvature of the Cobb angle of 10° and above shows an increase by 5° and more within six months, it is progressive (Sarwark & Davis, 2018; Kanter et al. 2018). Information regarding the length of the scoliosis arch, the degree of rotation, torsion and vertebral wedgedness is also of importance (Alayat et al, 2017; Le Berre et al. 2017). It is also recommended to assess the correctability of scoliosis, tested in the plane of maximal deformation, and bone age (the Risser test) (Minkara et al. 2018; Ng & Bettany-Saltikov, 2017) . This work is an attempt to answer the question whether all these parameters can be determined using both the Moiré spatial photogrammetry method and Exhibeon digital radiography, and whether ionizing radiological testing can be replaced by non-invasive spatial photogrammetry.

Therefore, the aim of the study was to assess the primary curvature of the spine with Moire's spatial photogrammetry and the Exhibeon digital radiology, and to compare both methods.

2. Methods

2.1 Participant (Subject) Characteristics

The study involved 28 children aged 7-18 years with scoliosis and scoliotic posture. The group of subjects was deliberate. The children enrolled at the Interschool Centre for Corrective and Compensatory Gymnastics in Starachowice (Poland). The tests were carried out in June 2011. All procedures performed in test involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The guardians of the children were informed about the purpose of the study and expressed written consent for their children's participation in the study.

2.2 Research Design

The study was non-invasive and free of charge. The patients willingly participated in the study, and perceived it as a concern about their state of health. Body posture and the spine were examined using the Moiré spatial photogrammetry method as well as Exhibeon digital radiography. Moiré's spatial photogrammetry method is based on the use of refraction of a light beam, for which a grid is used. The obtained image of the examined person's back is received via the optical system with a camera and then transferred to the analogue monitor and computer. Thanks to the appropriate card and programme, the computer performs proper postural analysis. The measuring stand consists of two blocks: a computer with a Frame Grabber mounted together with a monitor and printer, and a projection and reception device with a CCD/f=8mm camera and an analogue monitor. On the back of the examined individual, the spinous processes from C_7 to S_1, shoulder processes, lower angles of the shoulder blades and upper hind hip spikes were marked. Then, the examined person stood in a habitual position in the designated place with her back towards the device at a distance of 3.2 m. In order to avoid distortion, the height of the measuring device was adjusted so that the projective lenses were located in the middle of the trunk. Stripes were projected onto the back of the examined person, and the focus adjustment of the lens of the receiving projector allowed to obtain the Moiré image on the monitor screen.

2.3 Measures and Covariates

The measurement and focus of the image was carried out by an automatically controlled projection-receiving device. Further analysis took place without the participation of the subject. After entering the image and after pointing the mouse to the appropriate points of reference, it was properly processed. On the following screens, various options were displayed, some of which were available for selection by the examiner. Image analysis was performed separately for each body plane. The various graphic options presented during this analysis facilitated the selection of specific reference points, especially in uncertain cases. The device allowed to conduct analytical assessment of posture in three planes of the body: sagittal, frontal and transverse, that is, to precisely determine the abnormalities occurring within each of these planes. For this purpose, various parameters were established: length, depth and angle. In this manner, each dislocated section of the spine was measured and appropriate indicators showing inter-segmental relations were calculated. Measurements of subsequent parameters of the body's planes also gave information on the spatial positioning of the entire spine and its individual segments (Wilczyński et al. 2018). The computer developed a three-dimensional image of the back and carefully analysed 45 parameters. Parameters were determined in the frontal and transversal planes: the angle, direction and location of primary and secondary curvature. The study also used Exhibeon digital radiographs. Exhibeon works under the control of Linux and Microsoft Windows operating systems. Thanks to the browser, the radiologist could describe changes both in bone structure and soft tissues. Exhibeon supports 84 graphic formats of images compatible with DICOM, including animation formats presented in CINE mode. The image can be saved in popular jpg, png and bmp formats. Exhibeon is able to simultaneously cooperate with many image archives - PACS servers. The programme supports the DICOMDIR format and to search for images within the catalogue. It enables printing on DICOM printers and thanks to the device base, their configuration, is simple. Exhibeon digital radiology allows, among others, drafting the central cross-line of the spine on the computer screen, measuring the axial rotation angle of the vertebra and drafting the Cobb angle. Radiographs were performed in free standing position, in the anterior-posterior and lateral projection. X-ray image included the lumbar, thoracic and cervical spine, the chest and the pelvis including the hip joints. The Cobb angle was drawn on the spinal x-ray visible on the screen. On the basis of the size of the spinal curvature angle, scoliotic posture was determined at the level of: 1-9°, and scoliosis: ≥10°. Variables were verified in terms of normality using the Shapiro-Wilk test. To determine the relationship between the direction of primary curvature and its location and the age of the subjects, the Chi^2 test was performed.

The relationships between the size of the angle of curvature and the age of the subjects were analysed by screening analysis of variance. In the case of significant main effects or interactions, the Bonferoni test and the Tukey test were used as post hoc analysis methods. The relationship between the angle of primary curvature determined by the Moiré method and that determined by the digital method of Exhibeon radiology was analysed using multiple regression. P<0.05 was adopted as the assumed level of significance.

3. Results and Discussion

Scoliotic posture (1-9°) and scoliosis (≥10°) were isolated based on the size of the spinal curvature angle. According to the measurements using the Moiré method, there were 21 children with scoliotic posture (75.00%) and 7 with scoliosis (25.00%). According to measurements using Exhibeon digital radiology, there were 13 children with scoliotic posture (46.00%), less by 8 (29.00%), and 15 with scoliosis (54.00%), more by 8 (25.00%) in comparison to the results obtained using the Moiré method. The mean spinal curvature determined using the Moiré method was 8.25°, whereas the mean angle of curvature of the spine was 8.25°, and the difference was 4° (Tab. 1).

Table 1. Scoliosis as well as scoliotic posture and age

Moiré spatial photogrammetry method				
Variables	**Age**			
	7-11 years	**12-14 years**	**15-18 years**	**Total**
Scoliotic posture	6	10	5	21
% of total	21.00	36.00	18.00	75.00
Scoliosis	2	3	2	7
% of total	7.00	11.00	7.00	25.00
Total	8	13	7	28
% of total	29.00	46.00	25.00	100.00
Exhibeon digital radiology method				
Variables	**Age**			
	7-11 years	**12-14 years**	**15-18 years**	**Total**
Scoliotic posture	7	6	0	13
% of total	25.00	21.00	0.00	46.00
Scoliosis	1	7	7	15
% of total	4.00	25.00	25.00	54.00
Total	8	13	7	28
% of total	29.00	46.00	25.00	100.00

Among right-sided primary curvatures determined via the Moiré method (*dextroconvexa*), there were 16 cases (57.00%), and left-sided curvature (*sinistroconvexa*) concerned 12 cases (43.00%). The direction of the primary curvature was not related to the age of the subjects ($Chi^2 = 4.592974$, $p = 0.10062$) (Tab. 2). Among primary curvatures determined by the method of digital Exhibeon radiology, right-sided (*dextroconvexa*) ones were noted in 11 subjects (39.00%), thus in 5 (18.00%) less cases, while left-sided (*sinistroconvexa*) curvature was observed in 17 sunbects (61.00%), that is in 5 more (18.00%) than in the case of the Moiré method. The direction of the primary curvature was not related to the age of the subjects ($Chi^2 = 8.736204$; $p = 0.01268$) (Tab. 2).

Table 2. Direction of primary spinal curvature and the age of the subjects

Moiré spatial photogrammetry method				
Direction of curvature	**7-11 years**	**12-14 years**	**15-18 years**	**Total**
Left-sided	3	8	1	12
% of total	10.71%	28.57%	3.57%	42.86%
Right-sided	5	5	6	16
% of total	17.86%	17.86%	21.43%	57.14%
Total	8	13	7	28
% of total	28.57%	46.43%	25.00%	100.00%
$Chi^2 = 4.592974$; df = 2; $p = 0.10062$				

Exhibeon digital radiology method				
Direction of curvature	**7-11 years**	**12-14 years**	**15-18 years**	**Total**
Left-sided	6	10	1	17
% of total	21.43%	35.71%	3.57%	60.71%
Right-sided	2	3	6	11
% of total	7.14%	10.71%	21.43%	39.29%
Total	8	13	7	28
% of total	28.57%	46.43%	25.00%	100.00%
$Chi^2 = 8.736204$; df = 2; $p = 0.01268$				

Among the primary curvatures, thoratic scoliosis (*thoracalis)* was noted in 15 individuals (53.00%), lumbar scoliosis (*lumbalis*) in 10 (36.00%) and thoracolumbar scoliosis (*thoracalis-lumbalis*) concerned 3 cases (11%). The location of the curvature was not related to the age of the respondents ($Chi^2 = 4.664594$, $p = 0.32348$) (Table 3). Among primary curvatures determined by the Exhibeon digital radiology method, thoracic scoliosis appeared in 10 participants (36.00%), thus 5 (17.00%) less, lumbar scoliosis (*lumbalis*) totalled 6 participants (21.00%), which was lower by 4 (15.00%) and thoracolumbar scoliosis (*thoracalis-lumbalis*) occurred in 12 cases (43.00%), accordingly 9 (32.00%) more. The location of the primary curvature was not related to the age of the respondents ($Chi^2 = 7.258875$, $p = 0.12283$) (Tab. 3).

Table 3. Location of primary spinal curvature and the age of the subjects

Moiré spatial photogrammetry method				
Location of curvature	**7-11 years**	**12-14 years**	**15-18 years**	**Total**
Thoratic	5	5	5	15
% of total	17.86%	17.86%	17.86%	53.57%
Lumbar	3	6	1	10
% of total	10.71%	21.43%	3.57%	35.71%
Thoraco-lumbar	0	2	1	3
% of total	0.00%	7.14%	3.57%	10.71%
Total	8	13	7	28
% of total	28.57%	46.43%	25.00%	1
$Chi^2 = 4.664594$; df = 4; $p = 0.32348$				
Exhibeon digital radiology method				
Location of curvature	**7-11 years**	**12-14 years**	**15-18 years**	**Total**
Thoratic	1	4	5	10
% of total	3.57%	14.29%	17.86%	35.71%
Lumbar	3	3	0	6
% of total	10.71%	10.71%	0.00%	21.43%
Thoraco-lumbar	4	6	2	12
% of total	14.29%	21.43%	7.14%	42.86%
Total	8	13	7	28
$Chi^2 = 7.258875$; df = 4; $p = 0.12283$				

Screening analysis of variance showed significant relationships between the angle of the primary spinal curvature of the spine determined by X-ray with the age of the subjects. The Cobb angle increased with age ($p = 0.00040$). There was no such relationship between the primary angle of spinal curvature determined using the Moiré method and the age of the subjects ($p = 0.80737$) (Tab. 4).

Table 4. Angle of primary spinal curvature and the age of the subjects[1]

Screening analysis of variance	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	*p*
Moiré method	14.2102	2	7.1051	823.04	25	32.9216	0.216	0.80737
Exhibeon method	594.2102	2	297.1051	683.04	25	27.3216	10.874	**0.00040**

Multiple regression analysis showed a significant but low correlation between the primary curvature angle determined via the Moiré method (independent variable) and the primary curvature angle determined using Exhibeon digital radiology (dependent variable) (R = 0.45882525), (p = 0.01406) (Tab. 5).

Table 5. Multiple regression of dependent variable (of primary curvature angle – Exhibeon digital radiology method)[2]

Moiré spatial photogrammetry method									
Independent variables	**N**	**Aver**	**Med**	**Min**	**Max**	**Rang**	**Dev**	**Skewn**	**Kurto**
Angle of primary curvature	28	8.25	6.5	2	26	24	5.57	1.690	2.941
Direction of primary curvature	28	1.57	2	1	2	1	0.50	-0.305	-2.060
Location of primary curvature	28	1.57	1	1	3	2	0.69	0.817	-0.420
Exhibeon digital radiology method									
Dependent variables	**N**	**Aver**	**Med**	**Min**	**Max**	**Rang**	**Dev**	**Skewn**	**Kurto**
Angle of primary curvature	28	12.25	12	2	31	29	6.88	0.975	1.090
Direction of primary curvature	28	1.39	1	1	2	1	0.50	0.464	-1.928
Location of primary curvature	28	2.07	2	1	3	2	0.90	-0.148	-1.804
Summary of regression									
Multiple regression	**BETA**		**St. error BETA**	**B**		**St. error B**	***t* (26)**	***P***	
Constant term				11.551		1.206	9.574	**0.00000**	
Primary curvature angle - Moiré method	-0.459		0.174	-0.321		0.122	-2.633	**0.01406**	
R = 0.45882525; R^2 = 0.21052061; Adjusted. R2 = 0.18015602; F(1.26) = 6.9331, p < 0.01406; Standard estimation error = 6.2276									

The obtained results indicate moderate convergence of the variables of primary spinal curvature assessed using Moiré spatial photogrammetry and the Exhibeon digital radiography method. According to the digital radiation measurement by Exhibeon, the number of children with scoliotic posture was lower by 8 (29.00%), and with scoliosis, also by 8 (25.00%). The mean angle of the primary spinal curvature determined by X-ray was 4° higher. Among the original curvatures defined by X-ray, the number of right-sided curvature (*dextroconvexa*) was lower by 5 (18.00%), while the number of left-sided ones (*sinistroconvexa*) was greater by 5 (18.00%). Among primary curvatures determined by X-ray, the number of thoratic curvatures (*thoracalis*) was smaller by 5 (17.00%), lumbar curvature (*lumbalis*) by 4 (15.00%), and thoracolumbar (thoracalis-lumbalis) was lower by 9 (32.00%) cases. Although regression analysis showed a significant correlation between the angle of primary curvature determined by the Moiré method (independent variable) and its angle determined by the X-ray method (dependent variable), it was, nevertheless, low. Similar results were obtained by Kotwicki et al. (2004) examining 98 patients aged 5-22 with scoliosis and a Cobb angle of 10 to 18 degrees. It was demonstrated that the calculated scoliosis angle by spatial photogrammetry in all groups of patients was smaller than in the radiographs, and this discrepancy increased along with the increase of scoliosis angle. These authors believe that the reason for these differences are errors both during the examination and at the stage of calculating parameters by the computer programme. Similar results were also obtained by Stokes et al. (1989). In order to determine why topographic methods had shown a poor correlation with radiographically measured scoliosis in clinical studies, the accuracy of detection of the presence, side, apex, and magnitude of a scoliosis curve were determined topographically (by Moiré fringe photography and by projected raster photography) in 104 patients attending a scoliosis clinic. The size of the Cobb angle was determined to within +/- 5 degrees in 24% of cases using Moiré measurements, and in 27% by the raster technique.

The side of the scoliosis was incorrectly diagnosed by topography in ten patients with minimal or 'nonstandard' vertebral rotation. It was concluded that the presence, level, and side of a scoliosis curvature is well demonstrated by back surface topography in patients with 'standard' rotation, but the value of the scoliosis cannot be determined from topograms accurately enough for most clinical purposes. In turn, in other studies, there was some convergence in spinal assessment between measurements using spatial photogrammetry and X-ray (Schulte et al. 2008; Mangone et al., 2013; Degenhardt et al., 2017; Drzał- Grabiec et al., 2015). From these tests, it appears that to obtain reliable, repeatable and non-mistaken data, it is necessary to use a spatial photogrammetry device equipped with a good optical system, a spatial raster and a stepper motor, allowing to take several photos in a short time. To obtain reliable measurements, it is also necessary to accurately mark the points on the subject's body surface and carefully develop the image on the monitor screen. Moiré spatial photogrammetry results are not a substitute for medical examination, but may be a valuable supplement (Nowotny et al., 2002). The method does not replace radiological examination because it is an external measurement that does not inform about any structural changes or the level of maturation of the skeletal system. Radiographs of the whole spine together with the pelvis and hip joints are practically performed on two smaller cassettes. This excludes obtaining identical projection conditions and body layout unchanged in subsequent projections, and the need to adhere the body to the cassette is in conflict with the definition of habitual posture (Mrozkowiak & Strzecha, 2012). The Moiré spatial photogrammetry method is a non-invasive (using visible light) spatial measurement method of body and spinal posture. This test (without harmful ionizing radiation) can be repeated under various conditions and without limitation, It can be formed in cases in which there are not yet indications for radiological examination. In addition, it can be done in both habitual and corrected postures. It monitors the effects of therapy very well. However, in the diagnosis of advanced scoliosis, there is inaccuracy in determining the displacement of spinous processes relative to their actual axis. The small reliability and repeatability of the test results may be due to the poor quality of the measurement set, non-compliance with the principles of the technique and test methodology. A certain borderline discrepancy between the results of subsequent measurements of the same person is the norm, because posture is characterized by dynamic stability resulting, among others, from neurophysiological factors, diurnal and emotional variability, etc. The study of body and spinal posture using Moiré spatial photogrammetry should play a screening role (Stoliński et al., 2017). Nonetheless, it should borne in mind that digital radiography research by Exhibeon provides direct and illustrated information about the form and deviations from the norm, but only in two-dimensional projections. The spatial form can be measured metrically only at much larger technical expenditure, i.e. by stereographic X-rays or by computed tomography. It is also problematic to determine all aspects of spinal deformities (vertebral rotation) with only X-rays. Another minus of X-ray examination is the detrimental effect of ionizing radiation, which makes it impossible to take control photos at shorter intervals. Thus, it is difficult to control the course of therapy. Also, an extended series of X-ray images in screening cannot be performed. Despite many developed assessment methods, X-rays are still the most reliable method. Examination with the use of Moiré spatial photogrammetry does not replace spinal diagnosis using the Exhibeon digital radiology method, which is based on a different principle of operation, using, among others, bone system analysis (Nowotny et al. 2002). For the assessment of structural and other internal changes, the calculation of three-dimensional distortion of curvature from X-ray images is also used. In standard radiography, the scanning device can be used to simultaneously take photographs in the sagittal and frontal planes. From the trigonometric diagrams, three-dimensional scoliosis analyses are performed. In the three-dimensional geometric assessment of the vertebrae on anterior-posterior and lateral radiographs, three-dimensional assessment of individual vertebrae is made based on four points marked on the vertebrae. Two of them include the roots of the arches, and the next two, the centres of the upper and lower boundary plates, forming a tetrahedron. By combining each of the two orthogonal projections of the same circle, three-plane coordinates for each of these points are created. If the lordosis is found to deepen within the thoracic spine vertebrae, this method predicts the possibility of curvature progression. Three-dimensional computer tomography is the only method allowing to assess quantitative changes in scoliosis. In this technique, the stereoscopic CT image is subjected to mathematical operations enabling detailed analysis of quantitative changes within individual vertebrae. Nuclear magnetic resonance allows to assess the structure of the nerve tissue and the shape of the spinal canal without introducing contrast. This technique finds its greatest application in the diagnosis of congenital curvatures. Ultrasonography allows to assess thoracic torsion and rotation of individual vertebrae in a position lying face-down and standing. This technique is also useful in the assessment of post-operative treatment of thoracic torsion and spinal rotation. Digital radiology examination in scoliosis is still of paramount importance. However, protection against ionizing radiation which is not indifferent to health is obligatory. It means limiting radiological examinations to necessary cases and avoiding their frequent repetition. This especially applies to children and adolescents.

4. Conclusions

Regression analysis showed a significant but low correlation between the angle of primary curvature determined using the Moiré method (independent variable) and its angle determined by the X-ray method (dependent variable). Screening analysis of variance showed significant relationships between the angle of primary spinal curvature determined by X-ray with the age of the subjects. The Cobb angle increased with the age of the subjects. There was no such relationship between the angle of primary spinal curvature determined using the Moiré method and the age of the subjects. The obtained results show moderate convergence of primary spinal curvature variables assessed by Moiré spatial photogrammetry and the Exhibeon digital radiography method. Radiological examination in scoliosis is still of paramount importance.

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References

Alayat, M. S. M., Abdel-Kafy, E. M., & Abdelaal, A. M. (2017). H-reflex changes in adolescents with idiopathic scoliosis: A randomized clinical trial. *J Phys Ther Sci., 29*(9), 1658-1663. https://doi.org/10.1589/jpts.29.1658

Cho, N. I., Hwang, C. J., Kim, H. Y., Baik, J. M., et al. (2018). Referral patterns and patient characteristics at the first visit to a scoliosis center: A 2-year experience in South Korea without a school scoliosis-screening program. *J Neurosurg Pediatr, 2*, 1-7. https://doi.org/10.3171/2017.10.PEDS17348

De la Garza Ramos, R., Nakhla, J., Nasser, R., Schulz, J. F., Purvis, T. E., et al. (2017). Effect of body mass index on surgical outcomes after posterior spinal fusion for adolescent idiopathic scoliosis. *Neurosurg Focus, 43*(4), E5. https://doi.org/10.3171/2017.7. FOC US17342

Degenhardt, B., Starks, Z., Bhatia, S., & Franklin, G. A. (2017). Appraisal of the DIERS method for calculating postural measurements: An observational study. *Scoliosis Spinal Disord, 26*(12), 28. https://doi.org/10.1186/s13013-017-0134-y

Drzał- Grabiec, J., Truszczyńska, A., & Tarnowski, A. (2015). Comparison of parameters characterizing lumbar lordosis in radiograph and photogrammetric examination of adults. *J Manipulative Physiol Ther, 38*(3), 225-231. https://doi.org/10.1016/j.jmpt.2015.01. 001

Dunn, J., Henrikson, N. B., Morrison, C. C., Blasi, P. R. et al. (2018). Screening for Adolescent Idiopathic Scoliosis: Evidence Report and Systematic Review for the US Preventive Services Task Force. *JAMA, 9*, 319(2), 173-187. https://doi.org/10.1001/jama.2017.11669

Furlanetto, T. S., Sedrez, J. A., Candotti, C. T., & Loss, J. F. (2016). Photogrammetry as a tool for the postural evaluation of the spine: A systematic review. *World J Orthop, 18, 7*(2), 136-148. https://doi.org/10.5312/wjo.v7.i2.136

Gerdhem, P. (2018). CORR Insights®: Curve Progression in Adolescent Idiopathic Scoliosis Does Not Match Skeletal Growth. *Clin Orthop Relat Res, 476*(2), 437-438. https://doi.org/10.1007/s11999.0000000000000128

Ilharreborde, B. (2018). Sagittal balance and idiopathic scoliosis: does final sagittal alignment influence outcomes, degeneration rate or failure rate? *Eur Spine J., 24*. https://doi.org/10.1007/ s00586-018-5472-9

Jada, A., Mackel, C. E., Hwang, S. W., Samdani, A. F., et al. (2017). Evaluation and management of adolescent idiopathic scoliosis: A review. *Neurosurg Focus,* 43(4), E2. https://doi.org/10.3171/2017.7. FOCUS17297

Jin, J. (2018). Screening for Scoliosis in Adolescents. *JAMA,* 9, 319(2), 202. https://doi.org/10.1001/jama.2017.20372

Kanter, A. S., Tempel, Z. J., Agarwal, N., Hamilton, D. K., Zavatsky, J. M., et al. (2018). Laterality for Lateral Lumbar Interbody Fusion in Adult Scoliosis Surgery: The Concave Versus Convex Controversy. *Neurosurgery*, 18. https://doi.org/10.1093/neuros/nyx 612

Kotwicki, T., et al. (2004). Value of so-called computer posture evaluation method in children and adolescents. Poznań, 68-69.

Kumar, A., Kumar, S., Sharma, V., Srivastava, R. N., & Gupta, A. K., et al. (2017). Efficacy of Task Oriented Exercise Program Based on Ergonomics on Cobb's Angle and Pulmonary Function Improvement in Adolescent Idiopathic Scoliosis- A Randomized Control Trial. *J Clin Diagn Res., 11*(8), YC01-YC04. https://doi.org/10.7860/JCDR/2017/ 27497.10335

Le Berre, M., Guyot, M. A., Agnani, O., Bourdeauducq, I., Versyp, M. C., et al. (2017). Clinical balance tests, proprioceptive system and adolescent idiopathic scoliosis. *Eur Spine J., 26*(6), 1638-1644.

Mahaudens, P., Dalemans, F., Banse, X., & Mousny, M., et al. (2018). Gait in patients with adolescent idiopathic scoliosis. Effect of surgery at 10 years of follow-up. *Gait Posture, 11*(61), 141-148. https://doi.org/10.1016/j.gaitpost.2018.01.007

Mangone, M., Raimondi, P., Paoloni, M., Pellanera, S., & Di Michele, A., et al. (2013). Vertebral rotation in adolescent idiopathic scoliosis calculated by radiograph and back surface analysis-based methods: correlation between the Raimondi method and rasterstereography. *Eur Spine J., 22*(2), 367-371. https://doi.org/10.1007/s0 0586-012-2564-9

Minkara, A., Bainton, N., Tanaka, M., Kung, J., & DeAllie, C., et al. (2018). High Risk of Mismatch Between Sanders and Risser Staging in Adolescent Idiopathic Scoliosis: Are We Guiding Treatment Using the Wrong Classification? *J. Pediatr Orthop,* 2018, 22. https://doi.org/10.1097/BPO.0000000000001135

Morel, B., Moueddeb, S., Blondiaux, E., Richard, S., & Bachy, M., et al. (2018). Dose, image quality and spine modeling assessment of biplanar EOS micro-dose radiographs for the follow-up of in-brace adolescent idiopathic scoliosis patients. *Eur Spine J.,* 16. https://doi.org/10.1007/s00586-018-5464-9

Mrozkowiak, M., & Strzecha, M. (2012). Mora projekcyjna współczesnym narzędziem diagnostycznym postawy ciała. *Antropomotoryka, 60*, 33-47.

Ng, S. Y., & Bettany-Saltikov, J. (2017). Imaging in the Diagnosis and Monitoring of Children with Idiopathic Scoliosis. *Open Orthop J., 29*(11), 1500-1520. https://doi.org/10.2174/1874325001711011500

Nowotny, J., Gaździk, T., Zawieska, D., & Podlasik, P. (2002). Photogrammetry: Myths and reality. *Ortop Traumatol Rehabil, 30*(4), 498-502.

Sarwark, J. F., & Davis, M. M. (2018). Evolving Recommendations for Scoliosis Screening: A Compelling Need for Further Research. *JAMA*, 9, 319(2), 127-129. https://doi.org/10.1001/jama.2017.20190

Schulte, T. L., Hierholzer, E., Boerke, A., & Lerner, T., et al. (2008). Raster stereography versus radiography in the long-term follow-up of idiopathic scoliosis. *J Spinal Disord Tech., 21*(1), 23-28. https://doi.org/10.1097/BSD.0b013e318057529b

Simon, M. J. K., Halm, H. F. H., & Quante, M. (2018). Perioperative complications after surgical treatment in degenerative adult de novo scoliosis. *BMC Musculoskelet Disord,* 10, 19(1), 10. https://doi.org/10.1186/s12891-017-1925-2

Stasikelis, P. J., & Carpenter, A. M. (2018). Results of Casting in Severe Curves in Infantile Scoliosis. *J. Pediatr Orthop*, 31. https://doi.org/10.1097/BPO.0000000000001140

Stokes, I. A., & Moreland, M. S. (1989). Concordance of back surface asymmetry and spine shape in idiopathic scoliosis. *Spine, 14*(1), 73-78.

Stolinski, L., Kozinoga, M., Czaprowski, D., & Tyrakowski, M., et al. (2017). Two-dimensional digital photography for child body posture evaluation: Standardized technique, reliable parameters and normative data for age 7-10 years. *Scoliosis Spinal Disord,* 19, 12, 38. https://doi.org/10.1186/s13013-017-0146-7

Wilczyński, J., Habik, N., Bieniek, K., & Janecka, S., et al. (2018). Canonical correlations between body posture variables and postural stability in children with scoliosis and scoliotic posture. *Modern Applied Science, 12*(6), 58-69. https://doi.org/10.5539/mas.v12n9p19