

The validity of rasterstereography: a systematic review

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Abstract

To investigate and monitor the progression of scoliosis and other spinal deformities in patients following idiopathic scoliosis (IS), non-invasive and radiation-free techniques are recommended because of the need for repeated radiographs. In a clinical setting, spine parameters can be quickly, cheaply and easily assessed using rasterstereography (RS). To assess the validity of the radiation-free technique RS based on surface topography compared with radiographs. MEDLINE, the Cochrane Library and EMBASE were systematically searched for studies which investigate the validity of rasterstereography compared with x-ray measurements. Studies published between January 1, 1990 and July 31, 2013 in English, German and French were included. Studies dealing with magnetic resonance imaging were excluded. Twelve studies with 570 patients were included; these articles were published between 1990 and 2013. The majority of studies investigated patients with IS, but other spinal pathologies included were thoracic hyperkyphosis and Scheuermann's disease. With regard to the quality assessment criteria for the included studies, three out of twelve studies were evaluated using a twelve point scale and two used a scale with eleven points. We conclude that RS facilitates clinical practice by analysing the spinal column. It is completely radiation-free and could help to monitor scoliosis progression.

Introduction

Various subjective and objective methods have been developed to analyze and quantify scoliosis and other spinal deformities.¹⁻⁵ To evaluate the degree of deformity in the diagnosis and treatment of scoliosis and other spinal deformities examinations such as roentgenograms or computed tomography are frequently used.^{4,6,7} The use of two-dimensional anterior-posterior (a.p.) full-length spine radiologic investigation is accepted as the

mainstay to attest the medical diagnosis of idiopathic scoliosis, despite providing data only in two dimensions.⁸ The obvious disadvantage of such instrumental assessment method is the fear of increased carcinogenic risk and infertility from repeated exposure to ionizing radiation.⁹⁻¹²

The reason for the repeated radiographs is the requirement to measure the type, the flexibility and progression of the spinal curvatures in follow-up examinations in definite time intervals, which is obtained from two-dimensional a.p. spine radiographs.⁸ In the study of Nash and colleagues teenage girls with idiopathic scoliosis received over a treatment period of three years 22 roentgenograms.¹¹ One alternative examination suitable for this purpose is the light-sectioning method rasterstereography (RS), which is a precise, radiation-free and inexpensive and that is in routine clinical use in many scoliosis centers throughout the world.¹³ The method, which was developed by Drerup and Hierholzer in the 1980s, has been confirmed to be reliable both in pre- and postsurgical scoliosis patients for supplementing radiological and clinical examinations.¹⁴⁻¹⁸ By detecting anatomical landmarks with characteristic shape parameters – the vertebra prominens and the two spina iliaca posterior superior – coordinate data of back surface points and the line of symmetry can be determined.¹⁹ RS provides a reliable method for three-dimensional back shape analysis and reconstruction of spinal deformities.^{20,21} Several studies have evaluated the validity of RS compared with X-ray.²²⁻²⁵ Therefore, the aim of the present research was to evaluate the validity and accuracy of RS compared with X-ray in a systematic literature review.

Inclusion criteria and study identification

A systematic review of the literature was conducted in July 2013 using the PubMed data base of the National Library of Medicine, Embase and the Cochrane library for relevant trials indexed between January 1, 1990, and July 31, 2013. To be included in the literature review, articles had to meet the following criteria: i) original studies that investigated the validity of RS compared with X-ray measurement and ii) published between January 1, 1990, and July 31, 2013, in the English, French or German language. The following search items were used: rasterstereography, rasterstereographic AND X-ray, rasterstereography OR rasterstereographic. Studies were also excluded if they lacked standard X-ray measurement of the spine, e.g. MR tomography or a lack of evaluation of spine parameters or if they analysis of difference in leg length or

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pelvic obliquity.

Those papers satisfying these criteria were retrieved and included in the review.

Data abstraction

An abstraction form was created. Data were extracted independently on the basis of their full text by one reviewer, and verified by a second. The reviewers were not blinded to the journal or the author's name. The accuracy of the data abstraction was randomly confirmed in 10% of cases by the initial reviewer, as well as the second reviewer. The data abstraction form included: author's name, year of publication, investigated parameters, study population, x-ray measurement, statistical methods, outcomes and the QUADAS tool.

Methodological quality assessment

The studies included in this review were independently appraised for quality by two authors using the 14-item QUADAS appraisal

tool.^{26,27} It was developed to assess the diagnostic accuracy of primary diagnostic studies used in systematic reviews.²⁶

Using this tool, two reviewers (MM and SS) independently assessed the methodological quality of each included paper. Any disagreement in respect of study eligibility, data extraction or methodological quality assessment was settled through discussion between the reviewers. If no agreement was reached, a third reviewer (AS) acted as an adjudicator to determine the consensus.

Study identification

An appropriate search strategy was constructed to ensure that all relevant trials published during the study period were identified (Table 1). A total of 62 citations were identified through the literature search. All full-text articles were assessed for eligibility. Twelve studies were included in the review after this procedure (Figure 1).^{22-25,28-34}

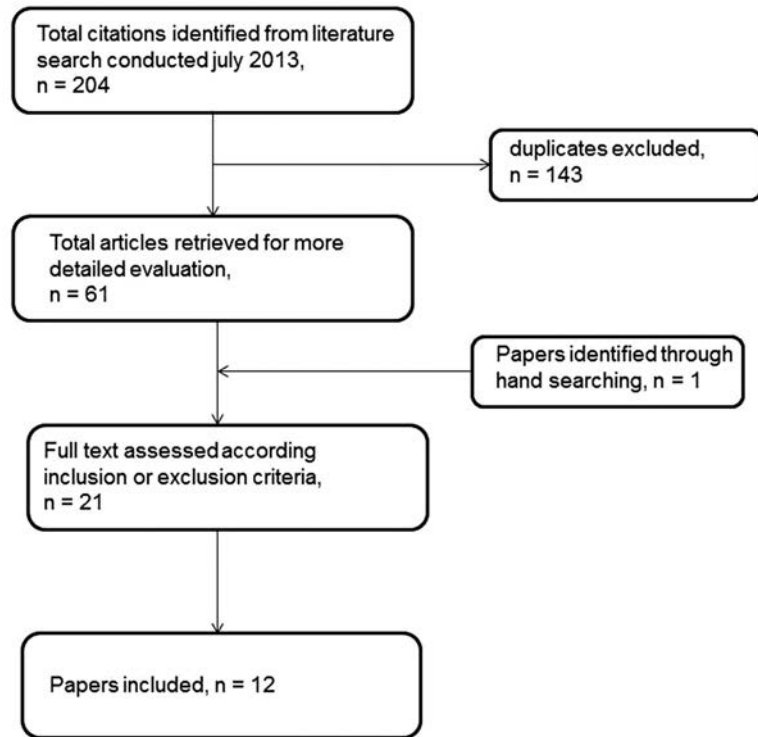


Figure 1. Flow of the studies through the systematic review.

Investigated parameters

The vertebral rotation was measured radiographically in nine studies out of the twelve investigated and compared with the rasterstereographic surface rotation respectively.^{14,15,22-25,28-40} The lateral deviation was the second most frequent parameter mentioned in three out of four studies by Hackenberg *et al.* with five mentions altogether.²²⁻²⁴ Kyphotic angle and lumbar lordosis were investigated triply. Torso overhang, apex height, lumbar

Table 1. Medline, Cochrane library and EMBASE were checked in July 2013 for appropriate material following the in- and exclusion criteria of this systematic review. The same keywords were used in all three databases.

Keywords	Medline	Cochrane	EMBASE
Rasterstereography	40	1	50
Rasterstereography OR rasterstereographic	46	1	51
Rasterstereographic AND x-ray	13	0	2
Total	99	2	103

Limits: publication date (1990-2013); "humans"; language (English, French, German).

Table 2. Parameters investigated in the primary studies.

	Vertebral rotation - surface rotation	Cobb angle	Torso overhang	Pelvic balance	Lateral deviation of spine	Kyphosis angle	Lumbar lordosis angle	Thoracic scoliosis	Apex height	Lumbar scoliosis	Total
Drerup <i>et al.</i> ³⁴	1	1			1				1		4
Liljenqvist <i>et al.</i> ²⁵	1	1	1	1		1	1				6
Hackenberg <i>et al.</i> ³⁰	1										1
Hackenberg <i>et al.</i> ²²	1				1						2
Hackenberg <i>et al.</i> ²³	1				1						2
Hackenberg <i>et al.</i> ²⁴	1				1						2
Schulte <i>et al.</i> ²⁹	1										1
Schulte <i>et al.</i> ²⁸	1	1			1						3
Weiss <i>et al.</i> ³¹						1 ^a					1
Crawford <i>et al.</i> ⁴⁰							1 ^b				1
Frerich <i>et al.</i> ³³						1	1	1		1	4
Mangone <i>et al.</i> ³²	1 ^c										1
Total	9	3	1	1	5	3	3	1	1	1	

^aAccording to Stagnara;⁴¹ ^bvia modified Cobb method;³⁹ ^cvia Raimondi method.³⁸

Table 3. Study population, X-ray measurement and statistical methods.

Study	Study population	X-ray measurement	Statistical methods
Drerup <i>et al.</i> ³⁴	113 patients with Cobb angles below 52 degrees	Anterior-posterior radiographs	RMS, standard deviation
Liljenqvist <i>et al.</i> ²⁵	95 patients with idiopathic scoliosis or scoliotic posture and 18 patients with thoracic hyperkyphosis and Scheuermann's disease	Anterior-posterior radiography in standing posture, vertebral rotation according to Perdriolle 1979 ³⁷	RMS, mean
Hackenberg <i>et al.</i> ³⁰	31 patients with thoracic, thoracolumbar and lumbar idiopathic scoliosis	Anterior-posterior radiography in standing posture, sagittal curvature according to Cobb 1948 and vertebral rotation according to Perdriolle 1979 ^{37,29}	Wilcoxon sign rank test, mean, standard deviation, minimum, maximum
Hackenberg <i>et al.</i> ²²	25 patients with severe idiopathic scoliosis (Cobb angle of 57° on average)	Standard anterior-posterior radiographs were digitized according to Drerup ^{4,15}	RMS
Hackenberg <i>et al.</i> ²³	52 patients with thoracic, thoracolumbar and lumbar idiopathic scoliosis	Anterior-posterior radiography in standing posture, digitized according to the method of Drerup ^{4,15}	RMS
Hackenberg <i>et al.</i> ²⁴	25 patients with idiopathic scoliosis	Anterior-posterior radiography in relaxed standing posture, digitized according to the method of Drerup ^{4,15}	RMS, range
Schulte <i>et al.</i> ²⁹	43 patients with idiopathic scoliosis	Digital radiometric rotation according to Drerup anterior-posterior radiographs, relaxed standing posture ^{4,15}	Wilcoxon sign rank test, mean, median, minimum, maximum, standard deviation
Schulte <i>et al.</i> ²⁸	16 patients with idiopathic right convex scoliosis	Radiographs digitized in accordance with Drerup's method ^{4,15}	RMS, maximum, correlation coefficient r2
Weiss <i>et al.</i> ³¹	53 patients (26 with Scheuermann's disease, 3 with thoracolumbar kyphosis, 15 with idiopathic kyphosis, 9 with kyphosis other origin)	Lateral x-ray	Mean, standard deviation, Pearson correlation, t-test,
Crawford <i>et al.</i> ⁴⁰	10 patients prepared for lumbar spine surgery	Relaxed clavicle position with hands placed over ipsilateral clavicles, standardized erect lateral x-ray positioning guide, lordotic angle via the modified Cobb-method using the superior endplates of L1 and S1 for reference	Nonparametric correlation coefficient Spearman's rho, mean, standard deviation, coefficient of variations
Frerich <i>et al.</i> ³³	64 patients with adolescent idiopathic scoliosis (AIS), Cobb angle between 10-50 degrees	Standard anterior-posterior radiograph	Correlation coefficient, average difference, range of difference
Mangone <i>et al.</i> ³²	25 patients with diagnosis of AIS	Vertebral rotation (Raimondi method regio) ³³	Kolmogorov-Smirnov test, one way ANOVA, intra-class-correlation coefficient (ICC), paired t-test, Spearman's correlation coefficient by rank (rs)
Total	570 patients		

SD, Standard deviation; RMS, root mean square.

scoliosis, thoracic scoliosis and pelvic position were recorded once each. Liljenqvist *et al.* investigated the highest number of parameters in their study (Table 2).²⁵

Study population

All studies investigated patients with spinal pathologies, *e.g.* idiopathic scoliosis (Table 3).^{14,15,22-25,28-40}

Statistics

The root mean square (RMS) was used for data evaluation in six studies. Mean values were also found in five studies. Weiss 2008, Schulte 2008, Frerich 2012 and Magone 2013 *et al.* used correlation coefficients for statistical comparison of the parameters (Table 3).^{28,31-33}

X-ray methods

Full-length radiographs of spines on two planes were made by Liljenqvist *et al.*²⁵ and Hackenberg *et al.*³⁰ These two authors were the only ones who determined vertebral rotation using the Perdriolle method (Table 3).

Study outcomes

The studies produced different results. The highest RMS for vertebral rotation was measured at 7.9 degrees. Smaller values for this parameter were found by Hackenberg *et al.* and Drerup *et al.*^{22-24,34} Crawford *et al.*⁴⁰ illustrated a non-significant association between the two methods using a *t*-test. Weiss *et al.*³¹ produced a significant difference which will be discussed later (Table 4).^{22-25,28-33,40}

QUADAS

Three studies scoring 12 points and two studies scoring 11 points on the QUADAS scale were evaluated; one study received four out of 14 possible points (Table 5).^{22-25,28-33,40}

Discussion

Our systematic review of twelve studies evaluating the validity of RS shows that the accuracy of this method varies. Liljenqvist

Table 4. Comparison between x-ray measurement and rasterstereography.

Study	Outcomes
Dreup <i>et al.</i> ²⁴	RMS deviation of the spinal midline (frontal) 3.6 mm (4.6 mm), RMS deviation of rotation 2.7 degrees (3.1°), SD of lateral curve amplitude 4.0 mm, SD of rotation amplitude 2.5, difference in apex height -4.6 mm, SD of Cobb angle 7.9°
Liljenqvist <i>et al.</i> ²⁵	Cobb angle: double-major scoliosis upper curvature 7.1° RMS, lower curvature 8.2°, thoracic scoliosis 7.8° RMS, scoliotic malposition 7.4° RMS. Thoracic kyphosis with Scheuermann's disease 5.6° RMS. Lumbar lordosis with Scheuermann's disease 14.0° RMS. Torso overhang mean statistical spread 1.07 cm. Pelvic balance mean statistical spread 0.65 cm. Rotation of apical vertebra on average 7.9° RMS (depends on type of scoliosis)
Hackenberg <i>et al.</i> ³⁰	Radiography apical vertebral rotation 29.2° preoperatively, 16.7° postoperatively, rasterstereographic max. surface rotation 16.5° preoperatively, 10.8° postoperatively, RMS preoperatively 14.8°
Hackenberg <i>et al.</i> ²²	Average RMS difference of lateral deviation 5.8 mm, for vertebral and surface rotation curves 4.4°
Hackenberg <i>et al.</i> ²³	Lateral deviation RMS difference 6.4 mm preoperatively, 3.4 mm postoperatively. Vertebral rotation (VR) without correction of trunk torsion RMS difference 5.3° preoperatively, 4.1° postoperatively, with correction of trunk torsion the RMS difference 4.5° preoperatively, 3.2° postoperatively
Hackenberg <i>et al.</i> ²⁴	Lateral deviation RMS difference 5.8 mm preoperatively, 4.5 mm postoperatively. Vertebral rotation without correction of torsion RMS difference of 5.5° preoperatively, 5.2° without correction of torsion postoperatively, vertebral rotation with correction of torsion RMS 4.8° preoperatively, 4.3° with correction of torsion RMS postoperatively.
Schulte <i>et al.</i> ²⁹	Group 1: Radiography maximum thoracic vertebral rotation 12.7° preoperatively, 6.8° follow-up. Secondary lumbar curve rotation 12.7° preoperatively, 10.9° at follow-up. Rasterstereography thoracic vertebral derotation 19.5° preoperatively, 10.4° follow-up. Secondary lumbar curve 9.6° preoperatively, 4.9° follow-up. Group 2: Radiography maximum lumbar vertebral rotation 21.9° preoperatively, 9.0° follow-up. Secondary thoracic curve vertebral rotation 5.0° preoperatively, 6.5° follow-up. Rasterstereography lumbar vertebral rotation 15.5° preoperatively, 6.0° postoperatively, secondary thoracic curve rotation 8.5° preoperatively, 11.3° postoperatively.
Schulte <i>et al.</i> ²⁸	RMS differences 3.2 mm for vertebral lateral deviation and 2.5 degrees for vertebral rotation. Correlation coefficient Cobb angle radiography and lateral deviation RMS 0.7 rasterstereography and rotation RMS 0.5 rasterstereography.
Weiss <i>et al.</i> ³¹	Average kyphosis angle radiography 49°, SD 17°, rasterstereography 63°, SD 13°, Pearson correlation of 0.78, significant difference of 14 degrees in the t-test (t=9.6 P<0.001).
Crawford <i>et al.</i> ⁴⁰	Lumbar lordosis radiography at baseline mean 56.4°, SD 10.7° preoperatively, mean 53.5°, SD 12.1° six week follow-up. Lumbar lordosis rasterstereography baseline mean preoperatively 46.2°, SD 11.5, mean postoperatively 6-week follow up 43.1°, SD 7.6. Lumbar lordosis rasterstereography and radiography correlation preoperatively, P=0.28 (not significant), postoperatively, P=0.26 (not significant).
Frerich <i>et al.</i> ³³	Lumbar curve average difference 9.40 degrees, range of difference 0-22, t=-0.758 Thoracic curve average difference 7.00 degrees, range of difference 0-19, r=0.872, Thoracic kyphosis average difference 10.6 degrees, range of difference 1-24, r=0.799, Lumbar lordosis average difference 8 degrees, range of difference 0-21, r=0.813
Mangone <i>et al.</i> ³²	Vertebral rotation (VR) by x-ray mean 9.93, SD 5.38, mean by RS 4.99, SD 3.50, t-test significant (t=10.48, P<0.0001. Lumbar VR by x-ray mean ± SD 9.18, SD 3.33, by RS mean 5.52, SD 3.01. Thoracic VR by x-ray mean 10.18, SD 5.90, by RS mean 4.82, SD 3.65. t=-0.52 entire spine, r=0.47, Cobb angle <30° (subgroup) t=-0.42 Cobb angle >30° (subgroup) t=-0.30 lumbar ventral rotation (subgroup) t=0.47 thoracic ventral rotation (subgroup)

SD, Standard deviation; RMS, root mean square.

reported an unacceptably high root-mean-square difference for a vertebral rotation of 7.9 degrees.²⁵ The RMS difference of vertebral rotation comparing digitized x-rays and rasterstereography was considerably lower in other studies.^{23,24,30,34} Postoperatively, Hackenberg *et al.* state problems when recording radiographic vertebral rotation according to the Perdriolle method.³⁰ A source of inaccuracy of vertebral rotation could occur due to *metallic implants hiding the contours of the vertebral bodies and pedicles*.²⁹

In some cases the patients had an idiopathic scoliosis located in the thoracic, thoracolumbar and lumbar parts of the spinal column. The highest Cobb angle of the scoliosis amounted to 92 degrees in Hackenberg.³⁰ Other spinal pathologies were hyperkyphoses and Morbus Scheuermann. Healthy volunteers were not examined.

Some authors investigated more than the parameters in Table 2. But they didn't match them with the radiographic or rasterstereographic correlate because some parameters are not directly comparable.

The statistical methods diverged. The RMS was frequently used as a statistical method. By calculating the RMS the square results were extracted; these have a smoothing effect on the absolute values.

Another problem when comparing absolute values became apparent in the study by Weiss.³¹ When the rasterstereographic kyphotic angle was compared to the radiometric kyphotic angle, a correlation of 0.78 according to Pearson was found. A t-test revealed a significant difference of 14 degrees (P<0.001) between the two methods, attributed to the fact that the radiometric kyphotic angle was measured from Th4 to Th12, but the rasterstereographic kyphotic angle was measured from Th1 to Th12.

The most studies scored seven or more of possible 14 points on the QUADAS scale, which means that these studies minimum have sufficient methodological quality.

However, quantitative evaluation of the validity of RS is difficult because RS is based on external measurements of the outer contour. RS will reference outer contours formed by spinous processes. Furthermore, it is influenced by overlying subcutaneous tissue that may affect the evaluation of parameters related to the internal morphology *e.g.* the surrounding soft tissue rotates less than the spine itself. In contrast, radiographic measures are derived directly from the internal morphology and consider variability of the spine.^{32,40}

Mohokum *et al.* however were able to show that a higher body mass index has no influence on the reliability of the method when used on healthy test volunteers.²⁰

To be able to further improve research, it is important to standardise all applied statistical

Table 5. All studies were analyzed according to QUADAS, the quality assessment tool for diagnostic studies.

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12	Item 13	Item 14	Total
Drerup <i>et al.</i> ³⁴	1	0	1	1	0	1	1	0	0	u	1	1	1	u	8
Liljenqvist <i>et al.</i> ²⁵	1	1	1	1	0	1	1	1	0	u	u	1	u	1	9
Hackenberg <i>et al.</i> ³⁰	1	1	1	1	u	1	1	0	1	u	u	1	1	0	8
Hackenberg <i>et al.</i> ²²	1	1	1	1	u	u	1	0	0	u	u	1	1	0	7
Hackenberg <i>et al.</i> ²³	1	1	1	u	u	u	1	1	1	u	u	1	0	0	7
Hackenberg <i>et al.</i> ²⁴	1	1	1	1	u	u	1	1	1	u	u	1	u	1	9
Schulte <i>et al.</i> ²⁹	1	1	1	1	1	1	1	1	1	u	u	1	1	1	12
Schulte <i>et al.</i> ²⁸	1	1	1	1	1	1	1	1	1	u	u	1	1	1	12
Weiss <i>et al.</i> ³¹	1	0	1	1	u	u	0	0	0	u	u	0	u	0	4
Crawford <i>et al.</i> ⁴⁰	1	1	1	1	1	1	1	1	1	u	u	1	1	1	12
Frerich <i>et al.</i> ³³	1	1	1	1	1	1	1	1	1	u	u	1	u	1	11
Mangone <i>et al.</i> ³²	1	1	1	1	1	1	1	1	1	u	u	1	u	1	11
Total	12	10	12	11	5	7	12	8	8	0	1	11	6	7	

u, unclear.

methods. Useful and suitable methods, in addition to mean values, standard deviation, scattering etc., would be a continuous evaluation of the correlation coefficient (*e.g.* Pearson) and the RMS. Ideally, in diagnostic studies involving rasterstereography, *i.e.* during an evaluation if the method appropriately detects spinal disorders according to current standards, a statement about the sensitivity and specificity should be made. Questions about influential factors such as the thickness of skin folds, body weight, body height, scars, etc. should be systematically included in further study designs.

Conclusions

Rasterstereography facilitates clinical practice by examining the spinal column. Further, it is completely radiation free and could help to monitor scoliosis progression. It can be used for screening examinations as well as for follow-ups and a diagnostic method for spinal scoliosis.

References

- Luk KD, Lee CF, Cheung KM, et al. Clinical effectiveness of school screening for adolescent idiopathic scoliosis: a large population-based retrospective cohort study. *Spine (Phila Pa 1976)* 2010;35:1607-14.
- Corona J, Sanders JO, Luhmann SJ, et al. Reliability of radiographic measures for infantile idiopathic scoliosis. *J Bone Joint Surg Am* 2012;94:e86.
- Klos SS, Liu XC, Lyon RM, et al. Reliability of a functional classification system in the monitoring of patients with idiopathic scoliosis. *Spine (Phila Pa 1976)* 2007;32:1662-6.
- Hierholzer E, Hackenberg L. Three-dimensional shape analysis of the scoliotic spine using MR tomography and rasterstereography. *Stud Health Technol Inform* 2002;91:184-9.
- Malmstrom EM, Karlberg M, Melander A, Magnusson M. Zebris versus Myrin: a comparative study between a three-dimensional ultrasound movement analysis and an inclinometer/compass method: intradevice reliability, concurrent validity, intertester comparison, intratester reliability, and intraindividual variability. *Spine (Phila Pa 1976)* 2003;28:E433-40.
- Cui G, Watanabe K, Nishiwaki Y, et al. Loss of apical vertebral derotation in adolescent idiopathic scoliosis: 2-year follow-up using multi-planar reconstruction computed tomography. *Eur Spine J* 2012;21:1111-20.

- Kuklo TR, Potter BK, Schroeder TM, O'Brien MF. Comparison of manual and digital measurements in adolescent idiopathic scoliosis. *Spine (Phila Pa 1976)* 2006;31:1240-6.
- Amzallag-Bellenger E, Uyttenhove F, Nectoux E, et al. Idiopathic scoliosis in children and adolescents: assessment with a biplanar X-ray device. *Insights Imaging* 2014;5:571-83.
- Ronckers CM, Land CE, Miller JS, et al. Cancer mortality among women frequently exposed to radiographic examinations for spinal disorders. *Radiat Res* 2010;174:83-90.
- Levy AR, Goldberg MS, Hanley JA, et al. Projecting the lifetime risk of cancer from exposure to diagnostic ionizing radiation for adolescent idiopathic scoliosis. *Health Phys* 1994;66:621-33.
- Nash CL, Jr., Gregg EC, Brown RH, Pillai K. Risks of exposure to X-rays in patients undergoing long-term treatment for scoliosis. *J Bone Joint Surg Am* 1979;61:371-4.
- Goldberg MS, Mayo NE, Levy AR, et al. Adverse reproductive outcomes among women exposed to low levels of ionizing radiation from diagnostic radiography for adolescent idiopathic scoliosis. *Epidemiology* 1998;9:271-8.
- Drerup B. Rasterstereographic measurement of scoliotic deformity. *Scoliosis* 2014;9:22.
- Drerup B. Principles of measurement of vertebral rotation from frontal projections of the pedicles. *J Biomech* 1984;17:923-35.
- Drerup B. Improvements in measuring vertebral rotation from the projections of the pedicles. *J Biomech* 1985;18:369-78.
- Drerup B, Hierholzer E. Automatic localization of anatomical landmarks on the back surface and construction of a body-fixed coordinate system. *J Biomech* 1987;20:961-70.
- Hierholzer E, Luxmann G. Three-dimensional shape analysis of the scoliotic spine using invariant shape parameters. *J Biomech* 1982;15:583-98.
- Hierholzer E, Schier F. Rasterstereography in the measurement and postoperative follow-up of anterior chest wall deformities. *Z Kinderchir* 1986;41:267-71.
- Lippold C, Moiseenko T, Drerup B, et al. Spine deviations and orthodontic treatment of asymmetric malocclusions in children. *BMC Musculoskelet Disord* 2012;13:151.
- Mohokum M, Mendoza S, Udo W, et al. Reproducibility of rasterstereography for kyphotic and lordotic angles, trunk length, and trunk inclination: a reliability study. *Spine (Phila Pa 1976)* 2010;35:1353-8.
- Schulein S, Mendoza S, Malzkorn R, et al. Rasterstereographic evaluation of interob-

- server and intraobserver reliability in post-surgical adolescent idiopathic scoliosis patients. *J Spinal Disord Tech* 2013;26:E143-9.
22. Hackenberg L, Hierholzer E. 3D back surface analysis of severe idiopathic scoliosis by rasterstereography: comparison of rasterstereographic and digitized radiometric data. *Stud Health Technol Inform* 2002;88:86-9.
 23. Hackenberg L, Hierholzer E, Potzl W, et al. Rasterstereographic back shape analysis in idiopathic scoliosis after posterior correction and fusion. *Clin Biomech (Bristol, Avon)* 2003;18:883-9.
 24. Hackenberg L, Hierholzer E, Potzl W, et al. Rasterstereographic back shape analysis in idiopathic scoliosis after anterior correction and fusion. *Clin Biomech (Bristol, Avon)* 2003;18:1-8.
 25. Liljenqvist U, Halm H, Hierholzer E, et al. [3-dimensional surface measurement of spinal deformities with video rasterstereography]. *Z Orthop Ihre Grenzgeb* 1998;136:57-64. [Article in German]
 26. Whiting P, Rutjes AW, Reitsma JB, et al. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. *BMC Med Res Methodol* 2003;3:25.
 27. Whiting PF, Weswood ME, Rutjes AW, et al. Evaluation of QUADAS, a tool for the quality assessment of diagnostic accuracy studies. *BMC Med Res Methodol* 2006;6:9.
 28. Schulte TL, Hierholzer E, Boerke A, et al. Raster stereography versus radiography in the long-term follow-up of idiopathic scoliosis. *J Spinal Disord Tech* 2008;21:23-8.
 29. Schulte TL, Liljenqvist U, Hierholzer E, et al. Spontaneous correction and derotation of secondary curves after selective anterior fusion of idiopathic scoliosis. *Spine (Phila Pa 1976)* 2006;31:315-21.
 30. Hackenberg L, Liljenqvist U, Hierholzer E, Halm H. [Scanning stereographic surface measurement in idiopathic scoliosis after VDS (ventral derotation spondylosis)]. *Z Orthop Ihre Grenzgeb.* 2000;138:353-9. [Article in German]
 31. Weiss HR, Elobeidi N. Comparison of the kyphosis angle evaluated by video rasterstereography (VRS) with x-ray measurements. *Stud Health Technol Inform* 2008;140:137-9.
 32. Mangone M, Raimondi P, Paoloni M, et al. 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* 2013;22:367-71.
 33. Frerich JM, Hertzler K, Knott P, Mardjetko S. Comparison of radiographic and surface topography measurements in adolescents with idiopathic scoliosis. *Open Orthop J* 2012;6:261-5.
 34. Drerup B, Hierholzer E. Back shape measurement using video rasterstereography and three-dimensional reconstruction of spinal shape. *Clin Biomech (Bristol, Avon)* 1994;9:28-36.
 35. Drerup B, Hierholzer E. Evaluation of frontal radiographs of scoliotic spines. Part II. Relations between lateral deviation, lateral tilt and axial rotation of vertebrae. *J Biomech* 1992;25:1443-50.
 36. Drerup B, Hierholzer E. Evaluation of frontal radiographs of scoliotic spines. Part I. Measurement of position and orientation of vertebrae and assessment of clinical shape parameters. *J Biomech* 1992;25:1357-62.
 37. Perdriolle R. *La Scoliose*. Paris: Maloine, SA; 1979.
 38. Weiss HR. Measurement of vertebral rotation: Perdriolle versus Raimondi. *Eur Spine J* 1995;4:34-8.
 39. Cobb JR. Outline for the study of Scoliosis. Instructional Course Lectures 5. Ann Arbor; J.W. Edwards: 1948. pp 261-275.
 40. Crawford RJ, Price RI, Singer KP. The effect of interspinous implant surgery on back surface shape and radiographic lumbar curvature. *Clin Biomech (Bristol, Avon)* 2009;24:467-72.
 41. Stagnara P, De Mauroy JC, Dran G, et al. Reciprocal angulation of vertebral 409 bodies in a sagittal plane: approach to references for the evaluation of kyphosis and 410 lordosis. *Spine (Phila Pa 1976)* 1982;7:335-42.