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Assessment of Vert-3D repeatability and reproducibility for evaluating the scoliosis of children with different nutritional profiles

Avaliação da repetibilidade e reprodutibilidade do Vert-3D para avaliação de escoliose de crianças em diferentes perfis nutricionais

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Abstract

Introduction: The Vert-3D is a radiation-free system which offers a three-dimensional view of the back's surface, providing a quantitative assessment of spinal curvatures. **Objective:** To verify the repeatability, inter-rater reproducibility, and correlation between Cobb angles and the results of the Vert-3D system version 1 in the evaluation of the front curvatures of the spine in children with different nutritional profiles. **Methods:** The sample was composed of 115 children who underwent posterior-anterior panoramic digital radiography of the spine and five evaluations with the Vert-3D system by three trained raters. **Results:** Version 1 of the Vert-3D system showed: (1) significant and moderate correlations of repeatability for arrows on the left (ICC between .54 to .83) and significant and moderate correlations for arrows on the right (ICC between .55 to .60) for only normal BMI; (2) significant correlations of inter-rater reproducibility for left arrows (ICC between .47 to .65), weak to moderate correlations for right arrows (ICC between .29 to .60), and no significance for obese samples; and (3) significant correlations ranging between .31 and .60 on the left side and non-significant correlations to the right side between Cobb angles and

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scoliosis arrows. **Conclusion:** High correlation levels solely on the left side decrease the possibility of system-use for the assessment of scoliosis.

Keywords: Evaluation. Spine. Topography. Child. Validity of Tests.

Resumo

Introdução: *O sistema Vert-3D fornece visão tridimensional da superfície das costas, possibilitando uma avaliação quantitativa das curvaturas da coluna vertebral, livre de radiação.* ***Objetivo:*** *Verificar a repetibilidade, a reprodutibilidade interavaliador e a correlação entre os ângulos de Cobb e os resultados da versão 1 do sistema Vert-3D na avaliação das curvaturas frontais da coluna vertebral de crianças com diferentes perfis nutricionais.* ***Métodos:*** *A amostra foi composta por 115 crianças, que foram submetidas à radiografia digital panorâmica póstero-anterior da coluna vertebral e cinco avaliações com o sistema Vert-3D, por três avaliadores treinados.* ***Resultados:*** *A versão 1 do sistema Vert-3D apresentou: (1) correlações significativas e moderadas de repetibilidade para flechas à esquerda (ICC entre 0,54 e 0,83) e correlações significativas e moderadas para flechas à direita (ICC entre 0,55 e 0,60), somente para IMC normal; (2) correlações significativas de reprodutibilidade interavaliador para flechas à esquerda (ICC entre 0,47 e 0,65), de fracas a moderas para as flechas a direita (ICC entre 0,29 e 0,60) e não significativa para os obesos; e (3) correlações significativas entre 0,31 e 0,60 para o lado esquerdo e não significativas para o lado direito entre os ângulos de Cobb e as flechas escolióticas.* ***Conclusão:*** *Os bons níveis de correlação apenas para o lado esquerdo diminuem as possibilidades de uso do sistema para avaliação da escoliose.*

Palavras-chave: *Avaliação. Coluna Vertebral. Topografia. Criança. Validade dos Testes.*

Introduction

The evaluation of the spine is very important for any clinical situation, such as when monitoring the curvature changes in the treatment of spinal deformities and for the planning of orthopedic surgical procedures (1). Usually, conventional radiography is the first choice of modality (2). However, the patient's exposure to a large amount of radiation constitutes a great disadvantage when securing radiographs, especially in cases with an early-onset of postural changes. Furthermore, X-ray examinations are not capable of measuring the asymmetry of the trunk, which often has the greatest importance for the patient rather than the radiographic position of the spinal column itself (3).

Aiming to minimize exposure to ionizing radiation and provide adequate and frequent monitoring of postural changes, noninvasive techniques meant to assess and analyze the progression of scoliosis have been recommended (4). Currently, several studies have investigated the validity of noninvasive instruments that use the stereograph for evaluation of the spine, such as the Formetric (5, 6), Quantec (7, 8), ISIS2 (3, 9) and Milwaukee systems (10). In Brazil, a system has been launched that analyzes the postural deviation of the spine by means of three-dimensional scanning, called the Vert-3D, which uses stereographic technology with structured light to provide a radiation-free examination and a three-dimensional view of the back's surface. However, thus far no reference has been found that indicates the system has been subjected to validation procedures.

It should be noted that in studies where the surface of the back is used as a reference for spinal evaluation, there has not been a mention of the anthropometric characteristics of the study population, and it appears that individuals within a normal body range prevail (6, 11) while obese individuals have been excluded (5). Perhaps this disparity is due to the fact that BMI is associated with a greater variability of trunk measures (12) dependent on palpation of anatomical reference points, and the amount of subcutaneous fat may influence palpation (13), causing variability in the evaluation results (14).

Thus, instruments that reduce the need for the manual marking of anatomical landmarks, such as the Vert-3D, can be important tools for physiotherapists to accurately evaluate overweight and obese individuals. Therefore, it is important to know the actual applicability of such instruments, specifically in relation to populations with differing nutritional profiles. With this in mind, the objectives of this study were: (a) to verify the repeatability; (b) to verify the inter-rater reproducibility; and (c) to correlate the Cobb angles with the results of the Vert-3D version 1 system, specifically in the assessment of the front curvatures of the spine in children with divergent nutritional profiles.

Methods

Sample

The sample size was determined through the Thometz et al. (15) study, admitting a 5% margin error and a 95% confidence interval. The following inclusion criteria were used: aged between 6 and 13 years old, were able to remain in the orthostatic position without assistance, provided a medical request for spinal radiography, and participated in all five tests with the Vert-3D system. Children who had previous surgery or congenital deformity in spinal structures were excluded. Initially, 119 children attending public health centers for whom spinal radiography had been requested were invited to participate in this study; however, four were lost—two for yielding a radiological examination with poor positioning, and two for not having completed the five tests with the Vert-3D system. The sample consisted of 115 children with a mean age of 10.9 ± 2.5 years; 53.9% (n = 62) were male.

In order to evaluate the validity of the Vert-3D system in various nutritional profiles, the sample was divided into three groups: low-weight and normal-weight, overweight, and obese. Each group was stratified according to the percentage of children belonging to these nutritional profiles (16). The low-weight group was analyzed together with the normal weight group because, when implementing the nutritional profile stratification according to the IBGE, the number of low-weight children was miniscule (n = 4), making it impossible to conduct a separate analysis of this group.

This study follows the National Health Council 466/12 resolution, and it was approved by the Ethics Research Committee of the Federal University of Rio Grande do Sul under ID number 19685. The children were included once a document of informed consent had been signed by their parent(s) and/or guardian(s).

Data collection

Anthropometric, radiographic, and topographic evaluations were performed on the same period of the day, and the examiners were blinded in regards to the experiment.

Anthropometric evaluation

Body mass and height were measured to calculate the body mass index (BMI). BMI was classified according to the international standard, stratified by age (17).

Radiographic evaluation

From the panoramic digital radiographs in the anteroposterior plane, the Cobb angles (18) were calculated with a mathematical routine developed in MATLAB 7.9 software. The scoliosis curvature angles were calculated with the steeper cranial vertebrae of the upper plateau and the steeper caudal vertebra of the lower plateau as references. All calculations were performed by two trained raters, and when the values between the evaluators differed more than 5º, a third rater performed a new evaluation (19). The Cobb angle was defined as the average of the two closest results.

Topographic evaluation

The topographic evaluation was performed with the Vert-3D topography system, developed by Miotec Biomedical Equipment Ltda located in Porto Alegre, Brazil.

To perform the evaluations, the children were placed with their backs facing the Vert3D equipment in the orthostatic position with a naked dorsum, arms outstretched along the body, barefoot, and positioned with a positioner aid (Figure 1).

The evaluator palpated and marked the spinous process of the seventh cervical vertebrae (C7), the second sacral vertebrae (S2), and the left and right posterior superior iliac spines (PSIS).

The assessments were performed by three raters previously trained in the method (Ra, Rb, and Rc), and each child was evaluated five times on the same day. For each assessment the markers were removed and each rater repeated the evaluation protocol, including: palpation, marking the anatomical points, child positioning and image capture. The assessment of repeatability employed data from two successive measurements by Ra (Measures 1 and 2) and Rb (Measures 3 and 4); for the inter-rater reproducibility, Ra's (Measure 1), Rb's (Measure 3), and Rc's (Measure 5) first measurements were used. In addition, to correlate the Cobb angles with the results of the Vert-3D, the measurements from Rc (Measure 5) were used.

The Vert-3D system

This system is composed of a computer, a projector, and a camera attached to a tower adjustable in height (Figure 1).

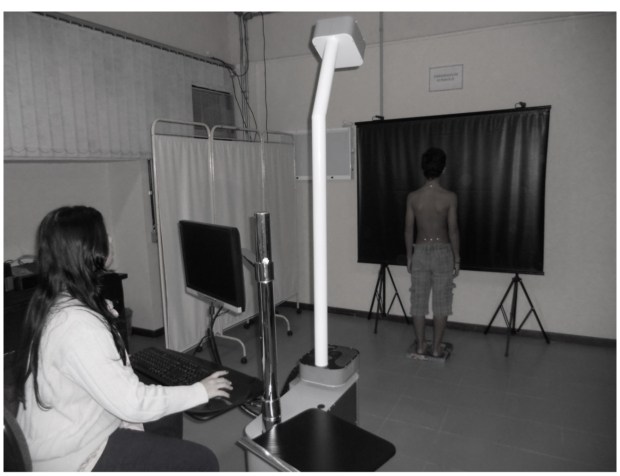

Figure 1 - The physical structure of the Vert-3D system, and child positioned for the exam.

This system projects a structured light pattern onto the individual's back, and the captured image is then analyzed by the Vert-3D system, which generates a bulge map and a curvature map. From this information the symmetry line is obtained, which is defined as the point at which there is no difference in the contouring and bending of both sides of each horizontal level, representing an estimate of the location of the spinous processes (20).

From this symmetry line, Version 1 of the Vert-3D system provides calculations of arrows and Vert angles of scoliosis; however, in this study only the data related to the arrows will be presented, since the results obtained with the angular measurements were unsatisfactory. For the scoliosis arrow calculations, a line uniting the initial curvature point (C7) with the lowest point showing the most lateral deviation, and another line uniting the final curvature point (S2) with the most superior point showing the most lateral deviation, were traced. These two lines are called strings, and the scoliosis arrows were obtained using the longest perpendicular distance (cm) between the strings and the symmetry line (Figure 2).

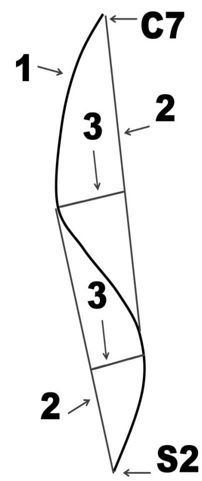

Figure 2 - Analysis of the symmetry line representation for the right and left arrows, 1 = Symmetry line; 2 = Strings; 3 = Scoliosis arrows.

Statistical analysis

Data normality was verified with the Kolmogorov-Smirnov test and descriptive data analysis was carried out in SPSS version 17 software. The inferential analysis was performed with the intraclass correlation coefficient (ICC), the Spearman correlation coefficient (rho), the Wilcoxon test, and the Friedman test ($\alpha = 0.05$).

The ICC values were classified as weak (ICC < 0.40), moderate (0.4 – 0.75), and excellent (ICC > 0.75), according to Fleiss (21). The rho values were classified as very low (< 0.1), low (0.1 – 0.3), moderate (0.3 – 0.5), high (0.5 – 0.7), very high (0.7 – 0.9) and practically perfect (between 0.9 and 1), according to Hopkins in Kotrlik (22).

Results

The group of children with a normal BMI or low weight (n = 69) had a mean BMI of 17.8 ± 2.3 kg/m², the group classified as overweight (n = 32) had a mean BMI of 22.4 ± 2.2 kg/m², and the group classified as obese (n = 14) had a mean BMI of 26.6 ± 4.0 kg/m². The total sample (n = 115) had a mean BMI of 20.2 ±4.0 kg/m².

In the analysis of repeatability, regardless of nutritional status, there was no difference between the two measures of the same evaluator. When the correlations were assessed, only the group with a normal BMI showed significant results for both the left and right scoliotic arrows (Table 1A and 1B).

Table 1A - Results of the Vert 3D Version 1 regarding to the scoliosis arrows repeatability in the various nutritional profiles (Evaluator A)

Arrows	Evaluator A				
	1º Median Evaluation (min.–max.)	2º Median Evaluation (min.–max.)	p (Wilcoxon)	ICC (IC95%)	p (ICC)
Normal BMI (n = 69)					
Right Arrow (cm)	0.13 (0.02-0.65)	0.14 (0.01-0.54)	0.283	0.550 (0.362-0.695)	<0.001*
Left Arrow (cm)	0.18 (0.03-0.91)	0.23 (0.01-1.07)	0.280	0.727 (0.593-0.822)	<0.001*
Overweight BMI (n = 32)					
Right Arrow (cm)	0.12 (0.01-0.31)	0.13 (0.03-0.34)	0.985	0.138 (-0.216-0.460)	0.222
Left Arrow (cm)	0.25 (0.10-0.75)	0.21 (0.02-0.88)	0.513	0.568 (0.278-0.763)	<0.001*
Obese BMI (n = 14)					
Right Arrow (cm)	0.14 (0.09-0.39)	0.10 (0.01-0.46)	0.124	0.430 (-0.108-0.773)	0.55
Left Arrow (cm)	0.21 (0.05-0.51)	0.18 (0.06-0.57)	0.826	0.835 (0.562-0.944)	<0.001*

Note: * Significant Correlation.

Table 1B - Results of the Vert 3D Version 1 regarding to the scoliosis arrows repeatability in the various nutritional profiles (Evaluator B)

Arrows	Evaluator B				
	1º Median Evaluation (min.–max.)	2º Median Evaluation (min.–max.)	p (Wilcoxon)	ICC (IC95%)	p (ICC)
Normal BMI (n = 69)					
Right Arrow (cm)	0.14 (0.01-0.69)	0.13 (0.02-0.64)	0.804	0.598 (0.422-0.731)	<0.001*
Left Arrow (cm)	0.19 (0.01-0.72)	0.21 (0.02-0.85)	0.221	0.665 (0.509-0.778)	<0.001*
Overweight BMI (n = 32)					
Right Arrow (cm)	0.11 (0.02-0.57)	0.12 (0.02-0.86)	0.640	-0.480 (-0.385-0.301)	0.604
Left Arrow (cm)	0.28 (0.04-0.82)	0.30 (0.01-0.64)	0.765	0.540 (0.194-0.723)	<0.001*
Obese BMI (n = 14)					
Right Arrow (cm)	0.12 (0.03-0.51)	0.06 (0.03-0.66)	0.778	0.090 (-0.444-0.578)	0.374
Left Arrow (cm)	0.27 (0.06-0.63)	0.19 (0.05-0.62)	0.778	0.558 (0.062-0.833)	<0.001*

Note: * Significant Correlation.

In the analysis of inter-rater reproducibility, regardless of nutritional status, there was no difference between the measurements of the three evaluators as well. When the correlations were calculated, only the right scoliotic arrow within the obese group showed no significant results (Table 2).

Regarding the scoliosis classification, six children had a "C" shape curvature on the right, 14 had a "C" on the left, and two were classified as having "S" shaped scoliosis; the remaining 93 children were classified as normal for not presenting Cobb angles above 10º.

When correlating Cobb angles with Vert-3D arrows, no correlation was found between the scoliosis arrows on the right and the Cobb angles. However, the scoliosis arrows on the left showed moderate to high correlations (rho ranging from .31 to .60) with the Cobb angles (Table 3).

Table 2 - Results of the Vert 3D Version 1 regarding to the inter-rater reproducibility of the scoliosis arrows in the various nutritional profiles

Arrows	Evaluator A Mean±DP	Evaluator B Mean±DP	Evaluator C Mean±DP	p (Friedman)	ICC (IC95%)	p (ICC)
Normal BMI (n=69)						
Right Arrow (cm)	0.13 (0.02-0.65)	0.14 (0.01-0.69)	0.13 (0.01-0.54)	0.904	0.599 (0.472-0.712)	<0.001*
Left Arrow (cm)	0.18 (0.03-0.91)	0.19 (0.01-0.72)	0.19 (0.02-0.84)	0.471	0.607 (0.481-0.719)	<0.001*
Overweight BMI (n=32)						
Right Arrow (cm)	0.12 (0.01-0.31)	0.11 (0.02-0.57)	0.12 (0.01-0.43)	1.00	0.287 (0.071-0.519)	0.004*
Left Arrow (cm)	0.25 (0.10-0.75)	0.28 (0.04-0.82)	0.24 (0.07-1.05)	0.804	0.649 (0.468-0.794)	<0.001*
Obese BMI (n=14)						
Right Arrow (cm)	0.14 (0.09-0.39)	0.12 (0.03-0.51)	0.14 (0.04-0.34)	0.424	0.075 (-0.196-0.462)	0.306
Left Arrow (cm)	0.21 (0.05-0.51)	0.27 (0.06-0.63)	0.27 (0.07-0.64)	0.424	0.470 (0.330-0.905)	<0.001*

Note: * Significant Correlation.

Table 3 - Results of correlation between scoliosis arrows of Vert 3D system and Cobb angles in different nutrient profiles for children with scoliosis

	BMI classification		rho	p
Cobb x right arrows	Normal (n=69)		-0.065	0.594
	Overweight (n=32)		-0.065	0.594
	Obese (n=14)		0.462	0.096
Cobb x left arrows	Normal (n=69)		0.310	0.010*
	Overweight (n=32)		0.478	0.006*
	Obese (n=14)		0.602	0.023*
Children with scoliosis				
	Cobb Angle (°)	**Arrows (cm)**	**rho**	**p**
Cobb x right arrows (n=8)	12.3 (10.4-21.9)	0.17 (0.07-0.54)	-0.119	0.779
Cobb x left arrows (n=16)	11.6 (10.0-19.0)	0.40 (0.06-0.84)	0.029	0.914

Note: * significant correlation ($p < 0.05$)

Discussion

The Vert-3D Version 1 system showed different results for repeatability and reproducibility, even with negative ICCs only for the right side, as well as correlations with Cobb angles, when analyzing the left and right sides, regardless of nutritional status. Negative ICCs indicate an opposite variability of the first group of measurements when comparing with the second group, indicating an undesirable result for measurements which one would expect to be similar. This discrepancy points to a difficulty in using the system for the evaluation of children with scoliosis. A large number of children had no obvious signs of scoliosis, with scoliosis arrows arriving at a maximum of 1 cm. In this sense, the system's error in measurement may be as large as the magnitude of the order in which the measurements were performed. An inaccurate estimation of the line of symmetry could also justify this discrepancy. Moreover, the nutritional profile does not appear to be responsible for the varied results of the left and right sides.

When assessing the influence of BMI on spinal evaluation with the Vert-3D system, moderate repeatability and inter-rater reproducibility were found for both the overweight and obese samples on the left (Tables 1A, 1B and 2). Berryman et al. (3) observed that in extremely obese patients or those with a large mass of muscular development, erros might occur to the results of topography system (specifically, the ISIS2 system), due to the difficulty of identifying and marking the necessary points of the bone. Furthermore, no studies have evaluated the influence of BMI on the variability observed during a topographic exam. Saad et al. (12), using computerized photogrammetry, found that increased BMI was associated with greater variability in the torso rotation measurements conducted by two examiners, and argued that this variability may be associated with palpation of the anatomic reference points. In the case of the Vert-3D system, the results changed when assessing the right arrows, regardless of nutritional profile, which shows that the body's condition does not seem to affect the results.

The descriptions of repeatability and inter-rater reproducibility in other topography systems found in the literature show different outcomes. Rankine et al. (23), using a new topography instrument named Milwaukee, found excellent correlations for the "Q" angle, with an ICC of 0.99 for repeatability and inter-rater reproducibility. Nevertheless, in this study the evaluation was performed with only one plastic mold of a patient with idiopathic scoliosis, which limits the result's generalization because evaluating a plastic mold eliminates many factors, such as the subject's movement, breathing, resting position, and the natural variability that exists within human posture.

Liu et al. (10), also using the Milwaukee instrument, reported excellent (ICC = 0.88) inter-rater reproducibility when appraising the spine of 10 subjects in the frontal plane. However, when the correlations between the same evaluator were verified, the levels shown were simply moderate (ICC = 0.50 and 0.56). A novel three-dimensional analysis technique of surface topography (BIOMODTM™ L system - AXS Medical SAS, Mérignac, France), which did not require manual body marking, showed adequate intra-rater reproducibility (kappa = 0.85) and inter-rater reproducibility (kappa = 0.62) for the classification of scoliosis groups. However, the assessment was solely qualitative in nature, and evaluators determined the scoliosis groups using the characteristics of a bulge map without presenting quantitative data representative of spinal curvature (2). The efficacy of the system for inter-rater reproducibility in the frontal plane is excellent in regards to the ICCs of angles designating thoracic scoliosis (ICC > 0.95) and thoracolumbar (ICC > 0.91). However, no significant correlation was found when assessing the inter-rater reproducibility of the lumbar curvature angles, which according to the authors, may be due to the small number of patients with this deformity (n < 9) (24).

As can be seen, in recent decades the evaluation of the torso's posture gained importance in clinical practice, and various non-invasive techniques have been developed and tested in order to overcome the limitations of manual and radiological methods (25). Despite this great effort, the true role of these measures in the clinical setting remains undefined, primarily because the real clinical applicability of these parameters is unknown (25). In an attempt to contribute to the applicability of these parameters, the correlation between radiographic findings and the results of the Vert-3D system was analyzed in this study. The Vert-3D Version 1 did not show a significant correlation between the right arrows and the right curvatures of the Cobb angles, but did show a correlation, though weak, between the left arrows and the left spinal curvatures of the Cobb angles.

This low correlation could be due to several factors, such as: (a) the different aspects of radiographic and surface topography evaluations; (b) little variation in scoliosis within the study population; (c) the inherent variability of the postural evaluation; and (d) the inherent difficulty of the Vert-3D system to provide results that strongly correlate with the radiological analysis.

During a qualitative exam, the torso's surface is structured in many ways in response to the frontal spinal changes presented by the subjects. In some individuals with lateral spinal bending, the posterior torso region remains symmetric, and thus, spinal changes are not identified in the torso's topography. In other cases, with a lateral bending of similar angulation, the torso's topography and the posterior torso region present greater lateral spinal change. Thus, the relation between the torso's surface and the spinal curvature is not directly related with the Cobb angle's magnitude. This corroborates with Drerup (26), which states that despite the surface topography providing reproducible results (which can be used to reduce exposure to X-rays), the correlation with the Cobb angle is poor and, therefore, the estimate of the Cobb angle from the topography results is often considered insufficient for clinical use. However, we should not disregard the fact that the topography may be useful for evaluation of the body's shape since, for patients with scoliosis, the aesthetics of the torso are more important than the spine's position. This aesthetic change is not measured in standard radiography (9). And, in that sense, these noninvasive exams could complement the radiographic evaluation.

However, assuming that other instruments of postural evaluation also demonstrated decent correlation between surface topography and radiography (27 - 30), other factors may have contributed to the low correlations seen in this study. The minor variations on scoliosis found in this sample is an important factor leading to decreased correlation. Therefore, the small spectrum in terms of the types of scoliosis studied is a limitation, and restricts the generalization of the results, especially for a population displaying a larger magnitude of scoliosis.

In summary, the high correlation levels exclusively on the left side, for both repeatability, inter-rater reproducibility, and the correlations between Cobb angles and scoliosis arrows, reduce the possibility of using the version 1 of Vert-3D system. However, in regards to the different nutritional profiles, there seems to be no limitation of the system in association with BMI. Considering the disparity of information between the surface topography in relation to bone structure, new studies are necessary to identify the most useful clinical parameters of the surface topography.

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