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The correlation between radiographic and surface topography assessments in three plane pelvic parameters

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Abstract.
BACKGROUND: Noninvasive rasterstereography has been reported as a helpful tool for assessing pelvic parameters. However, the validation and reproducibility of this tool are still questionable.
OBJECTIVE: To investigate the correlation between video rasterstereography device (VRD) and X-ray photography in terms of validity and reproducibility (inter- and intra-examiner reliability) in pelvic parameters.
METHODS: Thirty male and female healthy subjects with a mean age (26.9 $\pm$ 4.9 years) participated in this study. Subjects were examined by VRD for three pelvic parameters (pelvic torsion, pelvic tilt, and pelvic inclination). Measurements were conducted by three different examiners. Subjects were examined by X-ray radiography for the same pelvic parameters as well. Pearson correlation coefficient (r) was used to examine the validity and Intra-class correlation coefficient (ICC) was used to check intra- and inter-examiner reliability.
RESULTS: For pelvic torsion, tilt, and inclination the validity levels of VRD were 0.867, 0.996, and 0.930 ($P < 0.05$), respectively; while the intra- and inter-examiner reliability coefficients were 0.999, 0.999, and 0.998 and 0.990, 0.997, and 0.989, respectively.
CONCLUSION: The results of this study revealed that the VRD has both high validity and reliability in assessing the selected three pelvic parameters that reflect the three fundamental planes of movement in healthy subjects.
Further studies using VRD are recommended to assess low back pain-associated pelvic parameters.

Keywords: Surface topography, validity, reproducibility, pelvic parameters

1. Introduction

The pelvis is considered to be the base of the spine and the relationship between its parameters and overall spinal alignment is essential in the evaluation of spinal deformity. The optimal economic posture results from placing the working axis of gravity in a physiologic position. This posture greatly depends on the degree of congruence between spinal and pelvic parameters. The spatial position and shape of the pelvis are also essential to analyze sagittal balance of a subject [1]. Correlations between spinal and pelvic parameters have suggested that the pelvis is a major determinant in the prognosis of spinal disorders [2].

Differences of pelvic shape create numerous compensatory changes including postural scoliosis and lateral spinal tilting. Therefore, pelvic parameters (pelvic tilting, torsion,and obliquity) are important clinical outcomes at various situations such as scoliosis, leg-length inequality conditions, and other back dysfunctions [3].

The most extended means of assessment of pelvic

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Table 1
Demographic data for the study group are separated for males and females (mean $\pm$ standard deviation)

	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m2)
Total ($n = 30$)	26.9 $\pm$ 4.9	164 $\pm$ 8.9	67.4 $\pm$ 9.8	25.06 $\pm$ 2.7
Females ($n = 11$)	25.7 $\pm$ 3.9	154 $\pm$ 5.9	57.7 $\pm$ 7.3	24.3 $\pm$ 2.0
Males ($n = 19$)	27.9 $\pm$ 6.8	173 $\pm$ 6.0	76.5 $\pm$ 9.4	25.6 $\pm$ 3.4

Values are in mean $\pm$ SD, SD: standard deviation, n: sample size, BMI: body mass index.

parameters have been the frequent use of X-ray examinations that offer static 2-D analysis for 3-D motions with disadvantages of radiation hazards. Although radiological evaluation seems to be a superior external evaluation method, it needs a standard reference point to be defined. In addition, it has the disadvantage of exposure to radiation hazards [4]. This fact has raised fears of cancer risk and the possible negative effect on the future health of the patient and the clinician. Based on that, it is essential to consider reducing the risk of radiographs and to introduce a non-invasive method for assessment.

All static imaging devices used for posture analysis give a snap-shot of the posture. Mostly, this snap-shot is affected by anatomical, muscular, and even psychological factors affecting the real posture. Hence, there is still a need to investigate the reproducibility of such devices. Otherwise, the collected data will be meaningless [5].

In the last few decades, non-radiating devices such as video rasterstereography devices (VRD) have been developed for the non-invasive assessment of posture alignment. These devices have been developed for many essential reasons including the validity and reliability. However, these two criteria in some of them have not been sufficiently proven yet [6]. In addition, the three-dimensional VRD is a non-expensive and fast method to assess the human posture with minimal influence from the examiner. This is because the optical and non-contact characteristic of measurement that needs no markers or detectors on the skin surface [7].

The VRD is also one of the most advanced tools that produce graphical and clinical 3-D motion analytical information about the posture, spine, and pelvis. It provides clinical information to enhance diagnosis, build up treatments, and record treatment outcomes as well. It meets the objective of developing and producing a radiation-free, fast, and reliable measurement. Such a measurement complement x-ray measurement systems by using the combination of 3-D shape measurements and biomechanical modeling to reconstruct and display the spine structures as well as to measure spinal and pelvic parameters [8].

The validation of VRD in comparison to radiograph has been documented and limited in previous literature for assessment of spinal parameters in back disorders (low back pain, scoliosis, and kyphosis) [9,10]. However, in healthy subjects, the criterion based validity and reliability (intra- and inter-examiner reliability) of the three-dimensional form of analysis are still questionable for pelvic parameters (pelvic torsion, pelvic tilt, and pelvic inclination).

Therefore, the purpose of the present study was to investigate the correlation between VRD and X-ray photography in terms of validity and reproducibility (intra- and inter-examiner reliability) in pelvic parameters. As a consequence, a development of a non-invasive and objective 3-D back surface analysis for pelvic parameters could be established without exposure to radiation.

2. Methods

2.1. Subjects

Thirty healthy subjects from both genders participated in the study after signing institutionally approved consent forms prior to data collection. They were informed about the investigation and were recruited from the Faculty of Physical Therapy students and employees, Cairo University. The demographic data of the eligible subjects are shown in Table 1. The exclusion criteria were: true leg length discrepancy, previous spinal surgery, and associated pathologies that might interfere with maintaining an erect standing posture such as cerebellar disorders, inner ear disorders, and lower limb pathologies. This study was approved by the Ethical Committee of Faculty of Physical Therapy, Cairo University.

2.2. Procedure

One shot comparative study design was used in this study to test validity and intra- and inter-examiner reliability of VRD measurements. Rasterstereography device (Formetric 2, Diers International GmbH, Schlangenbad, Germany) was used to obtain photogrammetric 3-D surface analysis through automatic localization of anatomical landmarks (spina iliaca or lumbar dimple [SI], vertebra prominens [VP], left

Table 2
Pelvic parameters, shortcuts and corresponding geometry

Pelvic parameter	Shortcut	Explication
Pelvic torsion	P-Tors	The angle between the surface normals to the lumbar dimples (the SI posterior superior landmark).
Lateral pelvic tilting	P-Tilt	The angle between the vertical passing through DR and DL to the horizontal reference plane.
Pelvic inclination	P-inc (dimples)	Angle between the vertical and the tangent of lumbo-sacral inflection point.

SI: spina iliaca, DL: left crista iliaca posterior superior, DR: right crista iliaca posterior superior.

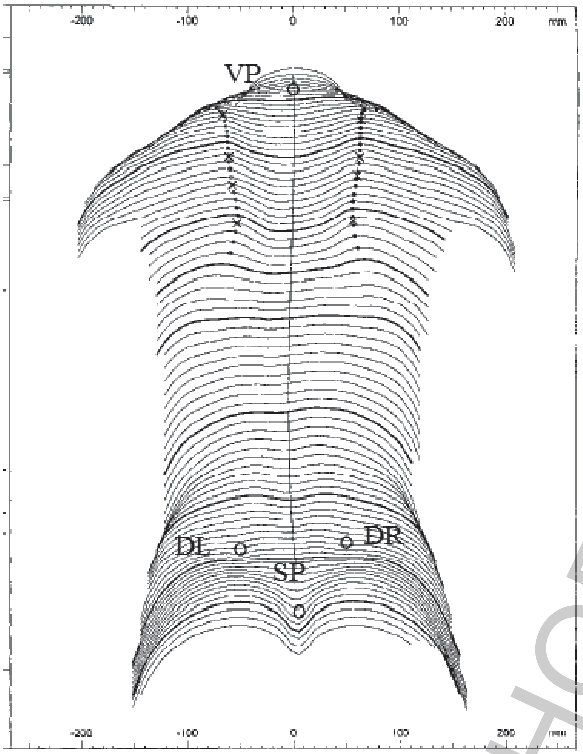

Fig. 1. The back surface and pelvis with transverse profiles.

crista iliaca posterior superior [DL], and right crista iliaca posterior superior [DR]) (Fig. 1). The localizations of these anatomical landmarks are the basis for an automatic reconstruction of the dorsal surface and pelvis shape [11].

For the purpose of validity; the subjects were enrolled in the radiology department to get both anterior-posterior and lateral radiographs. A remote X-ray machine (X – Omatic with regular screen, Kodak Eastman, New York) was used [12]. All radiographic films included the lumbosacral region and both hips. All radiographic measurements of pelvic parameters were calculated by a senior radiologist.

For the purpose of intra-examiner reliability; three repeated trials (T1, T2, and T3) on the same day were done by the first examiner (E_1). Those T_1, T_2, and T_3 measured the pelvic parameters (pelvic torsion, pelvic tilt, and pelvic inclination in transverse, frontal, and sagittal planes respectively) (Table 2). Each trial measured the three pelvic parameters for every subject with a time interval of 5 minutes between each trial. At the same time in the following two days and for the purpose of inter-examiner reliability, another two examiners (E_2 and E_3) measured the same pelvic parameters, with a time interval of 30 minutes between the two measurements for the same subject. The involved examiners were having more than 10 years of clinical and teaching experiences.

2.2.1. X-ray procedure

The subject was instructed to stand in stocking feet with their feet 6 to 8 inches apart, knees and hips straight, and body weight was distributed equally on both feet. The technician confirmed that subject's feet were perpendicular and equidistant to the Bucky frame, a femoral head-width apart and the buttocks were touching the Bucky frame lightly (a plumb line was used to assess the levelness of the X-ray [13]. The subject was positioned where a line connecting their heels would be parallel to the X-ray cassette. All measurements were made on coronal plane (anterior-posterior) and sagittal (lateral) exposure. Radiographs were taken on 91 cm (36 in) film at a 183 cm (72 in) tube to film distance. All pelvic parameters (pelvic torsion, pelvic tilt, and pelvic inclination in transverse, frontal, and sagittal planes respectively) were measured as described by Legaye et al. [14] and Irvin [15].

2.2.2. VRD procedure

The subject was positioned in front of the black background screen at a distance of 2 m from the center of the projection lens. The subject's back surface (including buttocks) was completely bare to prevent disturbing image structures. A free-standing posture was preferable and a rigid erect standing posture was avoided. The best moment for releasing image capture was the slightly breathed-out state. The subject was instructed to keep normal breathing and then to hold it for a few seconds while capturing the image. For pelvic torsion; the angle was measured between the surface of the lumbar dimples (Fig. 2(a)), for the lateral pelvic tilt; the angle was measured between the vertical lines

Table 3
Descriptive (mean ± SD) and measurement mean differences (one-way ANOVA) in three repeated trials and the three examiners

	$T_{1(\pm SD)}$	$T_{2(\pm SD)}$	$T_{3(\pm SD)}$	P	$E_{1(\pm SD)}$	$E_{2(\pm SD)}$	$E_{3(\pm SD)}$	P
Pelvic torsion (°)[a]	0.6 ± 3.9	0.9 ± 3.7	1.3 ± 4.1	0.785	0.6 ± 3.9	01.2 ± 3.8	0.8 ± 4.0	0.832
Pelvic tilt (°)[a]	0.7 ± 3.6	0.6 ± 3.1	0.9 ± 4.4	0.951	0.7 ± 3.6	1.1 ± 4.6	1.5 ± 3.5	0.734
Pelvic inclination(°)[a]	13.2 ± 5.4	11.5 ± 6.1	13.5 ± 5.9	0.360	13.2 ± 5.4	14.1 ± 6.2	13.1 ± 4.9	0.743

Values are in mean ± SD, SD: standard deviation, T: trial, E: examiner. [a]Angle.

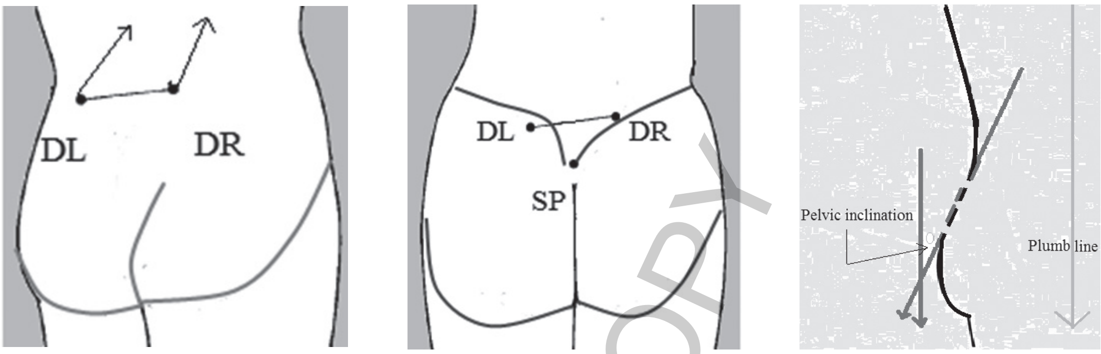

Fig. 2. The pelvic parameters in the back and lateral profiles of VRD images.

passing through DR and DL to the horizontal reference plane (Fig. 2(b)), and for pelvic inclination; the angle was measured between the vertical line and the tangent of lumbo-sacral inflection point (Fig. 2(c)).

2.3. *Statistical analysis*

Intra-class correlation coefficient (ICC) was calculated to check intra- and inter-examiner reliability of VRD. Pearson's correlation coefficient(r) was used to examine its validity. A one-way ANOVA and a repeated-measure ANOVA (rANOVA) were used to determine the measurement mean differences of the three examiners and the three trials respectively. Statistical version, 18 of software package for Windows (SPSS Incorporation, Chicago, IL) was used. The ICC provides the most conservative estimation of reliability because it gives high value only when the variance among trials for a particular individual is low, relative to the variance within a trial (6). ICC ranges from -1 to $+1$ (ICCs less than ± 0.40 indicate poor reliability, ± 0.40–0.75 indicate fair or good reliability, and ± 0.75–1.00 indicate excellent reliability) [17,18].

3. Results

The means and standard deviations for the three pelvic parameters were used to analyze intra-class reliability (intra- and inter-examiner reliability). There were no significant differences between the means from the first trial to the third trial of the first examiner in any pelvic parameter (pelvic torsion, tilt, and inclination; $p > 0.05$). The results also revealed that there were no significant differences between the means from the first examiner to the third examiner in any pelvic parameter (pelvic torsion, tilt, and inclination; $p > 0.05$) (Table 3).

ANOVA showed that ICCs to test inter-examiner reliability for pelvic parameters (pelvic torsion, tilt, and inclination) were 0.990, 0.997, and 0.989, respectively; with mean value was 0.992. This indicated that the calculated pelvic angles by VRD for each examiner were very reliable. A repeated-measure ANOVA showed that ICCs to test intra-examiner reliability for pelvic parameters (pelvic torsion, tilt, and inclination) were 0.999, 0.999, and 0.998 respectively; with a mean value was 0.998. This indicated that the calculated pelvic angles by VRD for each subject were very reliable (Table 4).

Pearson correlation coefficients (r) of all measurements of pelvic parameters for both VRD and X-ray showed strong correlations and statistical differences (pelvic torsion $r = 0.867$ and $p < 0.05$, pelvic tilting $r = 0.996$ and $p < 0.05$, and pelvic inclination $r = 0.930$ and $p < 0.05$). These indicated that VRD had a high validity in the measurements of the selected pelvic parameters (Table 5).

Table 4
ICC values for intra-examiner and inter-examiner repeated measures

	Intra-examiner ICC	Inter-examiner ICC
Pelvic torsion	0.999	0.990
Lateral pelvic tilting	0.999	0.997
Pelvic inclination	0.998	0.989
Mean	0.998	0.992

ICC: Intra-class correlation coefficient.

Table 5
Pearson's correlation(r) analysis between X-ray and VRD for pelvic parameters

	r	p
Pelvic Torsion	0.867*	< 0.05
Pelvic Tilt	0.996*	
Pelvic inclination	0.930*	

All pelvic parameters represented with p values < 0.05. *Statistical significance.

4. Discussion

The aim of this study was to investigate the correlation between VRD and X-ray photography in terms of validity and reproducibility (intra- and inter-examiner reliability) for measuring pelvic parameters (pelvic torsion, pelvic tilt, and pelvic inclination) among healthy subjects.

Based on the findings of the present study, the measurements obtained from VRD were highly correlated with X-ray measurements for pelvic parameters (pelvic tilting; $r = 0.86$, pelvic torsion; $r = 0.99$, and pelvic inclination; $r = 0.93$) in healthy subjects. The clinical implementation of this high correlation could minimize the radiation hazards for those subjects exposed to repeated X-ray examinations.

To the extent of our knowledge, few previous studies concerning the pelvic parameters investigated the validity of VRD in healthy subjects. However, the findings of this study were in agreement with the findings of many studies that investigated VRD validity in other body regions. Hackenberg et al. [19] found an excellent correlation between X-ray measurements and VRD measurements in patients with severe idiopathic scoliosis. Subsequently, the accuracy was good after posterior correction. They used the parameters of lateral vertebral deviation and vertebral rotation. Weiss and Elobeidi [20] confirmed that VRD could be used for prognostication of kyphotic patients. They found a significant correlation (= 0.78) between average kyphosis angle assessed by both X-ray and VRD.

The obtained high validity of VRD in measurement of selected pelvic parameters in our study is also in agreement with the results of Lippold et al. [21] who reported that the measurements of the body posture by mean of VRD were known to provide accurate information on the back shape and the sagittal profile without entailing radiographic strain for the patient. However, they measured the kyphotic angle, lordotic angle, and the pelvic inclination.

In the current study, three pelvic parameters (pelvic tilting, pelvic torsion, and pelvic inclination) were measured by VRD for two important reasons. Firstly, these three pelvic parameters express the three fundamental anatomical planes in which any pelvic abnormalities could be found. Secondly, pelvic parameters should not be used in isolation while assessing pelvic orientation because this could significantly influence clinical measures and consequently the validity of measurements [22,23].

The results of the current study demonstrated that all ICC values for all pelvic parameters ranged from 0.989 to 0.999. Interpreting ICC and defining its values which could be considered as the minimum for acceptable reliability is an arbitrary process. The lower limit of accepted reliability is considered to be higher than 0.6 [2]. The lower limit of acceptable ICC value depends upon the purpose of the study and both the high accuracy and precision of the optoelectronic system, as well as the short duration and automatic localization of anatomic landmarks [20].

Similarly, the reliability of VRD was examined in different studies. One of them included fifty-one healthy volunteers and revealed very good results for both intra-tester (0.921 to 0.992) and inter-tester reliability (0.979) [10]. However, the examined parameters were the kyphotic angle, lordotic angle, trunk length, and trunk inclination, while the pelvic parameters were not considered. These results were in line with an investigation by Goh et al. [9] where ICC values ranged between 0.98 and 0.99 in thoracic kyphosis. Another study was conducted to test intra-tester reliability of three repeated trials of pelvic parameters in low back pain dysfunctions by Schröder and Mattes [24], the authors reported high means of Pearson correlation coefficient and ICC which ranged from 0.62 to 0.99 for pelvic inclination, torsion, and tilting.

In the current study, a very high reproducibility (the mean values from 0.998 to 0.992) of VRD measurements with respect to the intra-examiner and inter-examiner reliability was demonstrated. This finding agreed with the reliability result of Guidetti et al. [25] who tested intra- and inter-day reliability in a collection of fifty healthy volunteers, they revealed that 0.830 and 0.824 were the mean values of intra- and inter-day reliability, respectively, for all examined parameters.

Our results concerning the intra-examiner and inter-examiner reliability were high compared to reliability results of this previous study. Moreover, the authors in this study examined the subjects twice a day for the purpose of intra-day reliability and once in two different days for the purpose of inter-day reliability, while in our study three examiners and three trials were used for the same purpose. Another helpful explanation for the same point could be the mean values in that study were calculated for eighteen spinal and pelvic parameters while in our study we selected three pelvic parameters. However, both could be classified as excellent degrees of reliability according to Rosner [18].

The indirect and non-invasive assessment of the spinal curvatures and pelvis position parameters by VRD were reported to offer valid, reliable, and helpful information throughout the screening and monitoring processes for out-patient low back pain rehabilitation [26]. The results of the current study agreed with the results of previously mentioned study, which were drawn from 192 healthy volunteers.

In another study investigating reliability coefficients of VRD, the authors reported that ICC values were ranging between 0. 99–0.91 and between 0.85–0.69 for the sagittal plane and the frontal planes respectively, while for the coronal plane it was 0.81 [27]. All the reported ICC values in this study were in line with our ICC values and were considered within the accepted reliability levels according to Jordan et al. [2]. Interestingly, in our study, we selected the three pelvic parameters (pelvic torsion, pelvic tilt, and pelvic inclination) that represent those three fundamental planes.

In addition, spine shape analysis by VRD found an association between low back pain and shapes of spinal parameters in the frontal plane and sagittal planes [28]. Furthermore, disorders of the sacroiliac joints are supposed to be the causes for about 20% of all low back complaints, but diagnosis is difficult [29]. In healthy subjects, the results of the current study reveal that VRD is highly reliable and highly valid in the non-invasive analysis of the selected pelvic parameters. An inference drawn from all these findings could throw light for further studies using VRD to assess shapes of pelvic parameters that are associated with low back pain.

5. Limitations

The number of subjects in the current study was based on reviewing of some literatures [21,25] concerning reproducibility and validation of VRD and we did not formerly use the statistical power of analysis. Based on this limitation, the current study could be considered a preliminary helpful study for future research.

Conflict of interest

The authors have no conflict of interest to report.

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