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Between-Day Reliability of DIERS Formetric 4D® Measurements and the Effects of Prolonged Sitting on Five Standing Positions in Healthy University Students

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SUMMARY

Background. The aim of this study was to investigate between-day reliability of postural measurements and to examine the effects of prolonged sitting (2 hours) on standing spinal posture using the DIERS Formetric 4D®device.

Methods. A test-retest reliability study was performed on 14 healthy university students to assess spinal shape parameters in five different standing positions. Between-day reliability was assessed using the intraclass correlation coefficient (ICC 3,1) and agreement was calculated with the standard errors of measurement and smallest real differences for the outcomes of interest. The paired t-test was used to compare the mean differences in standing spinal posture before and after prolonged sitting.

Results. For between-day reliability, trunk and pelvic imbalances and spinal deviation measures showed poor to moderate reliability when compared to other spine shape parameters that demonstrated moderate to good reliability. This study also showed a significant difference between pre- and post-sitting for 2 hours on specific spinal parameters except certain trunk/pelvic imbalances and spinal deviation measurements.

Conclusions. The DIERS Formetric 4D® device could be considered as a reliable tool for measuring spine shape parameters relating to localization, distance and spine curve measurements for certain standing postures in healthy male students. Our preliminary findings indicated a change in spinal shape parameters after 2 hours of prolonged sitting.

KEY WORDS

Back; healthy volunteers; posture; reproducibility of results; agreement.

INTRODUCTION

Spinal posture can be defined as the relationship between the position of different spinal segments with respect to one another and with respect to gravity (1). Clinically, spinal posture screening forms an integral part of musculoskeletal assessment (2). A recent study has shown that most desk-based workers and students tend to sit around 6.6 to 10 hours during the day (3). Prolonged sitting (> 8 hours/day) has been associated with various health concerns such as increased risk of obesity, cardiovascular and metabolic disorders as well as low back pain (4). Low back pain could be further exacerbated by faulty postures during sitting (5). Faulty postural habits might also predispose to postural abnormalities such as rounded shoulders, kyphosis, forward head, and altered proprioception in the spine (6). Consequently, postural rehabilitation plays an important part in the treatment of posture-related musculoskeletal disorders (7).

There are various methods for assessing posture such as pen and paper-based observation method, videotaping, photography, X-ray, computer-aided analysis, studying the projection of the center of gravity with the aid of a force platform, using strain-gauge sensors or accelerometers, silhouette-derived body shape models, and video rasterstereography (6, 8-10). Among these methods, surface topography, the study of the three-dimensional surface area of the back, using video rasterstereography has recently gained popularity for the assessment of postural deformities. The DIERS formetric 4D® device, employing video rasterstereography, is increasingly used in clinical practice because it allows one to observe the postural changes and shape parameters of the spine and pelvis without the hazards associated with radiography (11). Such a method is the gold standard for analyzing posture and spinal curves while standing.

During a typical six second scan of the back during static standing, 12 images of the posterior trunk are generated. The device then calculates around 40 shape parameters such as angles, distances, rotations, and deviations of the spine and pelvis while standing (11). A complex algorithm then produces a three-dimensional computerized image of an individual's spine (9). DIERS formetric 4D® spinal posture measurements have been found to be valid and reliable, in populations such as healthy adults and those with scoliosis (12-15). Moreover, trunk dimensions measured by the DIERS Formetric 4D® have been shown to be reproducible for angular and distance measurements (16). As the device also allows repeated measurements without causing any potential health risk, it is suitable for follow-up assessment of patients with kyphosis and other postural disorders (17). A recent study by Alzyoud *et al*. (2020) reported DIERS Formetric 4D® spine and pelvic shape measurements to be reliable in seven erect (standing) positions with variations in arm and feet position (15). However, the authors reported reliability of repeated measurements in a single session, and test-retest reliability of spine posture data measured with variations in arm/feet position needs further investigation. Moreover, there is also a dearth of literature on the effects of time dependent variations in spinal posture measured objectively with a device such as DIERS Formetric 4D®. Therefore, this study aimed to assess between-day reliability of spinal posture measurements using the DIERS formetric 4D® device and to examine the effects of prolonged sitting for 2 hours on spinal posture in five standing positions among healthy university students.

METHODS

Design, setting and ethical approval

A test-retest reliability study was performed on two occasions within a period of one week at a laboratory installed with the DIERS Formetric 4D® device at the Department of Physiotherapy, College of Health Sciences, University of Sharjah, United Arab Emirates. The study followed the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) (18) for documenting methods and results for between-day reliability of spine shape parameters. The University of Sharjah's Research Ethics Committee reviewed and approved the study (REC-20-02-05-03-S). The study meets the ethical standards of the Journal (19).

Participants

Fourteen healthy male students were recruited by convenience sampling through adverts, emails, and word of mouth at the University of Sharjah. The exclusion criteria were any history of spinal or extremity pain in the past three months that required intervention by a health professional, history of any developmental disorder (*e.g*., Scheuermann's/Calvé disease [juvenile osteochondrosis], adolescent idiopathic scoliosis, *etc*.), significant postural abnormalities, infection (*e.g*., tuberculosis of spine), tumor (*e.g*., multiple myeloma), arthritis/arthropathy, and/or surgery of the spine. Any other cardiorespiratory or neurological disorders that would interfere with participation in the study were excluded as well. Participants were pain-free according to the Nordic Musculoskeletal Questionnaire (extended version) (20) at the time of data collection.

Student volunteers, who met the inclusion criteria, gave an informed consent before participating in the data collection on two days within one week. Participants' demographic (age and year of study at the University) and anthropometric data (height measured with a stadiometer and weight with a weighing scale), relevant clinical history, and subjective physical activity levels (self-reported with IPAQ questionnaire short form) were documented. The IPAQ short version has been found to have an acceptable test-retest reliability and validity for vigorous activity and sitting, and moderate reliability for walking (21).

Session 1

All participants underwent the spinal posture screening with the DIERS formetric 4D® device and the spinal posture measurements were recorded in five different positions (day 1 test 1). Then they were asked to sit comfortably for two hours in a laboratory under the observation of the investigators. They were instructed not to stretch, stand, walk, or do any type of exercise during that period. The spinal posture screening was repeated after prolonged sitting to detect any changes in the posture (day 1 test 2).

Session 2 (after one week)

Participants underwent the spinal posture screening again with the DIERS formetric 4D® device at one time (day 2 test 1). However, pre- and post-assessment of spinal postural changes following prolonged sitting were not repeated.

Postural assessment

Spinal posture measurement was conducted by detecting the surface topography of the entire surface of the back in a static standing posture using the DIERS formetric4D® device (11). The laboratory was kept quiet and complete privacy of the subjects was ensured. Reflective stickers were placed on three bony landmarks by a physiotherapist (AMJ/AA) experienced in spinal palpation and postural assessment: the C7 spinous process and posterior superior iliac spines (PSISs; the right and left sacral dimples). In order to identify the C7 spinous process, the participants were asked to minimally flex their neck. Even though the detection of the mentioned landmarks was possible with the DiCAM III software, the reflective stickers were used to minimize the chance of any erroneous (automatic) detection of these landmarks (11). The reflective stickers were placed by the same assessor on both days.
Participants were required to stand bare feet with their heels touching the reference line marked on the treadmill, at about 220 cm from the light projector of the DIERS formetric 4D® device. They were asked to stand with their back facing the cameras. To maintain a static position of the head, their gaze was fixed in front at a reference point and this point was adjusted based on each participant's height. For all participants, the body was exposed from the occiput to the beginning of the inter-gluteal cleft. The spinal posture scanning was done three times, around 6 s for each scan, using the DiCAM III software at a frequency of 2 HZ. The postural screening was done in five different positions; the order of positions was randomized except for the neutral (normal) standing position which was assessed in the beginning of each test.
The positions used were: 1) neutral (normal) standing, 2) hands behind the ears with full external rotation and 90° abduction of the shoulder, 3) hands touching the ipsilateral medial end of the clavicle, 4) hands crossed on the chest, and 5) arms in front of the chest (**figure 1**). Among these, three positions were used in a previous study (15). Only three-dimensional reconstructed images, from the DIERS Formetric 4D® system software, were used for analysis.

Outcome measures

Of all the parameters provided by the DIERS software, only 11 that are commonly reported in the literature were chosen (**table I**) (12, 15, 22-24).

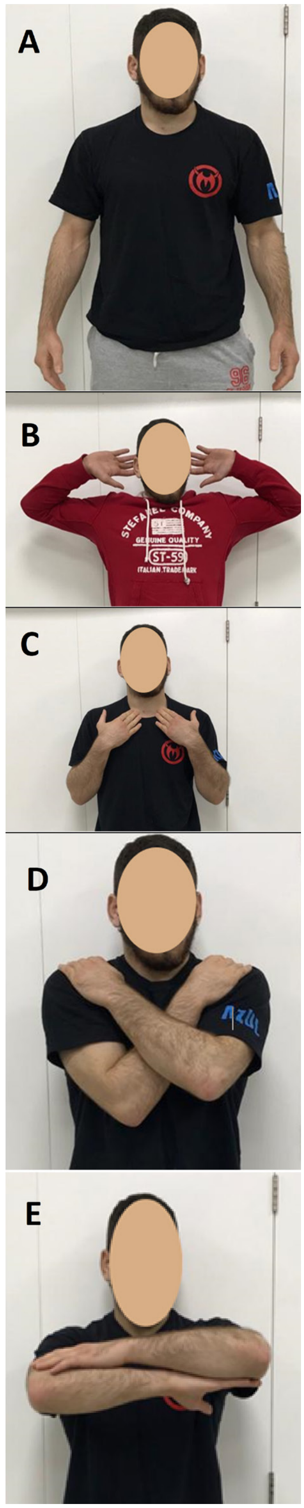

Figure 1. Five different standing positions used for spinal posture assessment in the study. (**A**) Neutral, (**B**) Hands behind the ears, (**C**) Hands on the clavicle, (**D**) Hands crossed on the chest and (**E**) Arms crossed in front.

Table I. Definition of spinal shape parameters obtained from the DIERS formetric4D® device.

Spine shape parameters	Unit	Definition
Localization and distance		
Trunk length	mm	VP to DM
Dimple distance	mm	DL to DR
Trunk and pelvic imbalances		
Sagittal imbalance (trunk inclination)	°	The angle between an external plumb line and the line connecting VP to DM
Coronal imbalance (trunk imbalance)	mm	Distance measured laterally between VP and DM
Pelvic obliquity (pelvic tilt)	mm	Height difference between DL and DR
Pelvic torsion	°	Surface normal torsions of DL and DR
Spinal Curve Measurements		
Kyphotic angle (max)	°	Angle formed between the surface tangents from ICT and ITL
Lordotic angle (max)	°	Angle formed between the surface tangents from ITL and ILS
Spinal deviations		
Vertebral rotation (+ max) (surface rotation)	°	The maximum value of the horizontal components of the surface normal on the symmetry line to the right
Vertebral rotation (rms) (surface rotation)	°	Root mean square (rms) of the horizontal components of the surface normal on the symmetry line
Vertebral rotation (amplitude) (surface rotation)	°	The maximal spinal torsion calculated from the maximal rotation to the right and to the left

DM: the center point between sacral dimple on the left and sacral dimple on the right; DL: sacral dimple left; DR: sacral dimple right; ICT: cervicothoracic transition point; ILS: lumbosacral transition point; ITL: thoracolumbar transition point; VP: vertebral prominence.

Statistical analysis

Spinal posture data were assessed for normality using the Shapiro Wilk's test. Between-day reliability were assessed using the intraclass correlation coefficient (ICC) (3,1) (two-way mixed effects, consistency, and single measurements) and 95% confidence intervals. ICC values < 0.50, 0.50-0.74, 0.75-0.89, and 0.90-1.0 were interpreted as poor, moderate, good, and excellent, respectively (25). The Standard Error of Measurement (SEM) was calculated by multiplying standard deviation by the square root of the ICC subtracted from 1 (26). The Smallest Real Difference (SRD) which indicates a real change beyond measurement error was calculated using the formula $1.96 \times SEM \times \sqrt{2}$ (27). Paired t-test was used to compare the mean differences in standing spinal posture between pre- and post-prolonged sitting. All statistical analyses were carried out using the statistical package for social sciences (IBM SPSS, version 25). The study findings are reported in accordance with the recommendations of Padulo *et al*. (2017) (28).

RESULTS

Out of 34 students who volunteered for the study initially, 14 were found eligible to participate. Out of the 14 only 13 were available for between-day comparisons. Reasons for exclusion of 20 students included lack of interest and/or time, or no response to follow-up emails. The included participants had mean age of 19.79 (± 1.53; standard deviation) years. Their mean and standard deviation values for height, bodyweight and BMI were 176.14 ± 6.15 cm, 70.92 ± 10.07 kg, and 22.90 ± 3.44 kg/m² respectively. IPAQ scoring revealed an average of 2322 MET– minutes/week based on their physical activity levels throughout the previous week before data collection. Spinal shape parameters for the five standing positions are summarized as means and standard deviations in **tables II-IV**.

Between-day reliability

ICCs for between-day reliability of spine shape measurements of all five positions are described in **table V**, and corresponding SEM and SRD values are reported in **tables VI**. Between-day reliability for neutral position showed poor to moderate between-day reliability (ICC: 0-0.70) for most spine shape parameters. The rest of the positions also showed poor to moderate reliability for most parameters. The smallest SEM value was for vertebral rotation (root mean square) (0.67°) for the hands behind the ears position and the largest SEM value was for trunk length (15.11 mm) (**table VI**).

Table II. Summary of DIERS measurements for the five standing positions recorded on day 1 (test session 1). The mean represents the average of three repeated measurements for each standing position.

Mean ± SD Day1 Test 1											
Standing position	**Localization and distance**		**Trunk and pelvic imbalances**				**Spinal Curve Measurements**		**Spinal deviation**		
	TL (mm)	**DD (mm)**	**PObl (mm R)**	**CI (mm R)**	**SI (°R)**	**PTor (°)**	**LL (°)**	**TK (°)**	**VRrms (°)**	**VRamp (°)**	**VR_{max} (°R) (~ T_2)**
1. Neutral	470.36 ± 17.31	92.19 ± 8.93	3.24 ± 2.58	5.21 ± 3.18	3.45 ± 1.89	2.57 ± 1.70	45.19 ± 10.07	47.29 ± 5.55	3.60 ± 1.47	10.81 ± 6.74	4.81 ± 7.82
2. Hands behind the ears	476.02 ± 20.55	92.21 ± 9.00	2.93 ± 1.88	6.55 ± 5.38	3.19 ± 2.19	2.40 ± 1.18	47.67 ± 9.51	39.19 ± 8.53	4.57 ± 1.94	7.98 ± 3.24	3.43 ± 1.77
3. Hands on the clavicle	466.97 ± 17.28	91.43 ± 9.36	3.38 ± 2.50	6.24 ± 6.50	1.98 ± 1.41	2.36 ± 1.165	50.41 ± 8.12	46.10 ± 6.68	3.55 ± 1.65	9.24 ± 0.88	3.5 ± 3.59
4. Hands crossed on the chest	466.45 ± 18.77	92.24 ± 9.08	3.29 ± 2.66	7.12 ± 5.13	1.67 ± 1.31	3.05 ± 1.50	56.07 ± 8.78	48.31 ± 5.51	3.93 ± 1.50	10.14 ± 3.88	4.40 ± 3.53
5. Arms crossed in front	464.54 ± 16.53	92.56 ± 9.20	3.31 ± 2.25	7.70 ± 7.40	2.41 ± 2.20	3.15 ± 1.45	59.23 ± 7.89	48.10 ± 7.88	4.20 ± 1.38	11.38 ± 0.67	4.41 ± 3.0

CI: coronal imbalance; DD: dimples distance; LL: lumbar lordosis; PObl: pelvic obliquity; PTor: pelvic torsion; SI: sagittal imbalance; TK: thoracokyphosis; TL: trunk length; VRamp: vertebral rotation amplitude; VRmax: vertebral rotation maximum; VRrms: vertebral rotation rms.

Table III. Summary of DIERS measurements for the five standing positions recorded on day 1 (test session 2). The mean represents the average of three repeated measurements for each standing position.

Mean ± SD Day1 Test 2											
Standing position	**Localization and distance**		**Trunk and pelvic imbalances**				**Spinal Curve Measurements**		**Spinal deviation**		
	TL (mm)	**DD (mm)**	**PObl (mm R)**	**CI (mm R)**	**SI (°R)**	**PTor (°)**	**LL (°)**	**TK (°)**	**VRrms (°)**	**VRamp (°)**	**VR_{max} (°R) (~ T_2)**
1. Neutral	470.21 ± 19.65	89.67 ± 10.16	4.07 ± 2.06	6.75 ± 5.16	3.50 ± 1.59	2.24 ± 1.08	43.18 ± 7.67	47.12 ± 5.05	3.56 ± 1.27	10.52 ± 5.22	4.68 ± 5.63
2. Hands behind the ears	468.57 ± 17.20	91.69 ± 9.12	4.19 ± 2.27	7.24 ± 5.33	3.29 ± 1.91	2.55 ± 1.10	47.62 ± 9.74	39.86 ± 1.91	5.05 ± 2.49	7.67 ± 2.33	3.88 ± 2.88
3. Hands on the clavicle	465.17 ± 16.52	91.45 ± 9.02	3.31 ± 2.12	6.29 ± 7.37	2.21 ± 1.81	2.43 ± 1.64	50.23 ± 8.91	46.14 ± 4.80	3.52 ± 1.36	8.98 ± 2.68	3.05 ± 2.56
4. Hands crossed on the chest	463.40 ± 18.41	91.52 ± 9.14	3.02 ± 1.50	6.86 ± 5.09	1.45 ± 1.37	3.07 ± 2.07	54.93 ± 8.86	47.83 ± 4.54	4.02 ± 1.25	10.60 ± 3.42	3.79 ± 3.61
5. Arms crossed in front	462.00 ± 17.23	92.23 ± 8.79	4.38 ± 2.45	7.26 ± 8.35	2.72 ± 2.17	2.85 ± 0.77	57.90 ± 7.62	46.38 ± 6.31	3.79 ± 1.80	9.72 ± 3.65	2.82 ± 2.66

CI: coronal imbalance; DD: dimples distance; LL: lumbar lordosis; PObl: pelvic obliquity; PTor: pelvic torsion; SI: sagittal imbalance; TK: thoracokyphosis; TL: trunk length; VRamp: vertebral rotation amplitude; VRmax: vertebral rotation maximum; VRrms: vertebral rotation rms.

Table IV. Summary of DIERS measurements for the five standing positions recorded on day two (test session 1). The mean represents the average of three repeated measurements for each standing position.

Mean ± SD Day 2 Test 1											
Standing position	**Localization and distance**		**Trunk and pelvic imbalances**				**Spinal Curve Measurements**		**Spinal deviation**		
	TL (mm)	**DD (mm)**	**PObl (mm R)**	**CI (mm R)**	**SI (°R)**	**PTor (°)**	**LL (°)**	**TK (°)**	**VRrms (°)**	**VRamp (°)**	**VRmax (°R) (~ T_2)**
1. Neutral	470.87 ± 22.13	92.42 ± 10.16	3.83 ± 2.46	5.08 ± 3.33	2.85 ± 1.28	2.74 ± 0.72	49.88 ± 8.56	44.86 ± 9.36	4.32 ± 1.86	15.17 ± 12.28	6.18 ± 10.64
2. Hands behind the ears	469.62 ± 19.22	92.49 ± 10.02	3.33 ± 1.90	5.62 ± 4.33	3.21 ± 2.06	3.05 ± 1.54	47.82 ± 7.23	40.31 ± 10.96	4.62 ± 1.56	8.54 ± 2.23	3.87 ± 2.56
3. Hands on the clavicle	466.04 ± 19.94	92.46 ± 10.17	3.56 ± 2.32	5.56 ± 4.33	2.41 ± 1.73	2.42 ± 0.83	48.44 ± 6.74	46.40 ± 6.97	3.60 ± 1.28	9.79 ± 2.45	3.38 ± 2.62
4. Arms crossed on the chest	465.6 ± 19.59	92.51 ± 10.10	3.00 ± 2.26	5.77 ± 3.78	1.51 ± 1.18	2.79 ± 1.70	52.49 ± 7.66	47.90 ± 5.45	3.87 ± 1.40	10.18 ± 2.88	3.59 ± 3.12
5. Arms crossed in front	464.6 ± 19.90	91.74 ± 9.91	3.28 ± 1.90	8.08 ± 5.91	2.87 ± 1.66	2.72 ± 1.57	53.33 ± 7.22	44.82 ± 10.17	4.64 ± 1.93	13.87 ± 8.92	4.36 ± 3.67

CI: coronal imbalance; DD: dimples distance; LL: lumbar lordosis; PObl: pelvic obliquity; PTor: pelvic torsion; SI: sagittal imbalance; TK: thoracokyphosis; TL: trunk length; VRamp: vertebral rotation amplitude; VR_{max}: vertebral rotation maximum; VRrms: vertebral rotation rms.

Table V. Between-day reliability (day 1 test 1 vs day 2 test 1; intraclass correlation coefficients [ICCs] ± 95% confidence intervals) of spine shape measurements from five standing positions for 13 male participants

	Localization and distance		**Trunk and pelvic imbalances**				**Spinal Curve Measurements**		**Spinal deviation**		
Standing position	**TL (mm)**	**DD (mm)**	**PObl (mm R)**	**CI (mm R)**	**SI (°R)**	**PTor (°)**	**LL (°)**	**TK (°)**	**VRrms (°)**	**VRamp (°)**	**VRmax (°R) (~T_2)**
1. Neutral	*0.42 (0,0.78)	0.56 (0.02, 0.84)	*0.13 (0,0.62)	*0.004 (0, 0.55)	0.61 (0.12, 0.86)	*0 (0,0.46)	0.50 (0.01, 0.81)	0.54 (0.02, 0.83)	0.70 (0.27, 0.90)	*0 (0, 0.4)	*0 (0, 0.46)
2. Hands behind the ears	0.52 (0.02, 0.82)	*0.52 (0, 0.82)	*0.16 (0, 0.64)	*0.41 (0, 0.77)	0.89 (0.71, 0.96)	*0.47 (0, 0.80)	0.68 (0.21, 0.89)	0.87 (0.64, 0.95)	0.67 (0.19, 0.88)	*0.27 (0, 0.71)	0.69 (0.26, 0.89)
3. Hands on the clavicle	0.63 (0.15, 0.87)	0.60 (0.09, 0.92)	0.79 (0.45, 0.93)	*0.49 (0, 0.81)	*0.11 (0, 0.62)	*0.37 (0, 0.76)	0.67 (0.21, 0.88)	*0 (0, 0.27)	0.70 (0.29, 0.89)	0.85 (0.58, 0.95)	0.70 (0.29, 0.89)
4. Arms crossed on the chest	0.85 (0.58, 0.95)	0.56 (0.02, 0.84)	*0 (0,0.43)	*0.38 (0, 0.76)	*0.0 (0, 0.53)	*0.02 (0,0.56)	0.67 (0.18, 0.89)	0.90 (0.71, 0.97)	0.74 (0.33, 0.91)	0.71 (0.29, 0.90)	0.81 (0.49, 0.93)
5. Arms crossed in front	0.70 (0.25, 0.90)	0.71 (0.28, 0.90)	0.72 (0.31, 0.91)	0.69 (0.24, 0.89)	0.51 (0.01, 0.81)	*0.22 (0, 0.67)	0.54 (0.01, 0.83)	0.83 (0.54, 0.94)	0.68 (0.25, 0.88)	*0.09 (0, 0.59)	0.76 (0.38, 0.92)

CI: coronal imbalance, DD: dimples distance, LL: lumbar lordosis, PObl: pelvic obliquity, PTor: pelvic torsion, SI: sagittal imbalance, TK: thoracokyphosis, TL: trunk length, VRamp: vertebral rotation amplitude, VRmax: vertebral rotation maximum, VRrms: vertebral rotation rms. *Negative ICC values are substituted with zero.

Table VI. Standard errors of measurement (SEM) and smallest real difference (SRD) values showing between-day (BD; Day 1 Test 1 *vs* Day 2 Test 1; n = 13) agreement measures of spine shape measurements for five positions.

Standing position	Localization and distance				Trunk and pelvic imbalances								Spinal Curve Measurements				Spinal deviation					
	TL (mm)		DD (mm)		POBl (mm R)		CI (mm R)		SI (°R)		PTor (°)		LL (°)		TK (°)		VRrms (°)		VRamp (°)		VR_{max} (°R) (~ T_2)	
	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD	SEM	SRD
1. Neutral	15.11	41.89	6.28	17.42	2.34	6.48	3.25	9.01	1.00	2.78	1.38	3.82	6.57	18.21	5.22	14.46	0.91	2.51	10.62	29.45	9.86	27.32
2. Hands behind the ears	13.66	37.86	6.55	18.16	1.73	4.79	3.74	10.36	0.68	1.87	0.99	2.74	4.78	13.25	3.52	9.74	0.67	2.80	2.36	6.55	1.22	3.38
3. Hands on the clavicle	7.11	19.70	5.27	14.60	2.80	7.77	3.16	8.77	0.86	2.38	0.80	2.21	5.32	14.74	3.07	8.50	0.92	2.56	1.76	4.87	3.06	8.47
4. Hands crossed on the chest	7.30	20.23	6.35	17.60	2.67	7.40	3.53	9.80	1.26	3.49	1.58	4.37	4.67	12.95	1.70	4.71	0.73	2.03	1.81	5.01	1.44	4.00
5. Arms crossed in front	9.94	27.57	5.13	14.22	1.08	3.00	3.70	10.25	1.35	3.74	1.33	3.69	5.08	14.07	3.73	10.35	0.95	2.63	6.23	17.27	1.62	4.48

CI: coronal imbalance, DD: dimples distance, LL: lumbar lordosis, POBl: pelvic obliquity, PTor: pelvic torsion, SI: sagittal imbalance, TK: thoracokyphosis, TL: trunk length, VRamp: vertebral rotation amplitude, VRmax: vertebral rotation maximum, VRrms: vertebral rotation rms.

The neutral standing (ICC: 0-0.70) and hands behind the ears (ICC: 0-0.89) showed low between-day reliability for most spine shape parameters compared to other positions. In summary, nearly all spinal shape parameters demonstrated nearly moderate to good between-day reliability except for trunk and pelvic imbalances (ICC: 0-0.89), and vertebral rotation amplitude (ICC: 0-0.85) parameters for the five standing positions.

Effects of prolonged sitting on spine shape parameters

This study also showed a significant difference between pre- and post-sitting for 2 hours for specific spinal parameters (**table VII**). Except for certain measurements related to pelvic imbalances (pelvic obliquity/tilt and torsion) and spinal deviations (vertebral rotation parameters) in a few positions, all other spinal parameters show a significant difference following sitting for 2 hours.

DISCUSSION

The aim of our study was to assess between-day reliability of postural measurements using the DIERS Formetric 4D® device and to examine the effects of prolonged sitting on standing spinal posture. Though previous studies have shown the DIERS Formetric 4D®device to be reliable (12-15, 23, 24) for spinal and pelvic measurements of neutral standing, only one study has reported within-day reliability of these parameters for different standing positions (15). The results generated from this study demonstrate between-day reliability and agreement measures as well as the effect of prolonged sitting on these parameters for five different standing positions including different upper limb positions.

Between-day reliability

Degenhardt *et al*. (2017) found good to excellent reliability for localization/distance and spinal curve measurements with ICC values ranging from 0.87 to 0.98 for between-day reliability for standing neutral position (11) as compared to ICC values of 0.42 to 0.61 for the same position and parameters in our study. SEM values reported by Degenhardt *et al*. (2020) for certain trunk and pelvic imbalances (*e.g.*, coronal imbalance, pelvic obliquity/tilt and torsion) ranged from 1.19 to 3.21 for neutral position, in stationary scans and repetition of scans on 5 days during 1 week. All their scans were taken at the same time during the 5 days. When

Table VII. Results of paired t-test comparisons of spine shape measurements between test 1 (pre-sitting) and test 2 (post-sitting) of day 1.

Standing position	Spinal deviation		Spinal curve measurements				Trunk and pelvic imbalances		Localization and distance		
	TL (mm)	DD (mm)	PObl (mm)	CI (mm R)	SI (oR)	PTor (°)	LL (°)	TK (°)	VRrms (°)	VRamp (°)	VR_{max} (°) (~ T_2)
	P values										
1. Neutral	**< 0.001**	**0.007**	**0.007**	0.053	**0.003**	0.087	0.094	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
2. Hands behind the ears	**0.045**	**< 0.001**	0.408	**0.021**	**< 0.001**	0.107	**0.007**	**0.001**	0.076	0.577	0.188
3. Hands on the clavicle	**< 0.001**	**< 0.001**	0.156	**< 0.001**	**0.017**	0.081	**< 0.001**	**0.011**	**0.001**	**0.011**	**< 0.001**
4. Hands crossed on the chest	**< 0.001**	**< 0.001**	0.393	**0.013**	0.178	0.178	**0.001**	**< 0.001**	**0.001**	**< 0.001**	**< 0.001**
5. Arms crossed in front	**< 0.001**	**< 0.001**	**0.037**	**0.001**	**0.004**	0.649	**0.007**	**< 0.001**	**0.009**	0.149	**0.048**

P values < 0.05 are shown in bold.

compared to our study, SEM values for the same parameters and position ranged from 1.38 to 3.25. Out of all those values, it would be interesting to note that SEM values for between-day reliability for trunk and pelvic imbalances (*e.g.*, coronal imbalance, pelvic obliquity/tilt and torsion) and vertebral rotation (root mean square) parameters were found to be the one with the most similarity. Tabard-Fougere *et al.* (2017) also found almost similar ICC values for pelvic obliquity (0.27) and vertebral rotation (root mean square) (0.88) compared to those of our study (pelvic obliquity [0.13] and vertebral rotation (root mean square) [0.70]) (23). Furthermore, in agreement with our findings, Tabard-Fougere *et al*. (2017) also reported almost similar SEM values for trunk length (13.1 mm), pelvic obliquity (3.7 mm) and vertebral rotation (root mean square) (1.4°). The use of reflective markers in this study could be one of the reasons for the variability of results encountered as compared to the study by Degenhardt *et al*. (2017) which did not use reflective markers. In the study by Gipsman *et al*. (2014), reflective stickers were used and then adjusted in case of any discrepancies noticed after images were generated (9). Previous studies have indicated better reliability with automatic landmark detection vs manual detection (29). Soft tissue involvement in the lumbar region has also been identified as a factor for differences in reliability and error of measurements although BMI (30) has not been found to have any effect in the results.

Perhaps, except for standing in neutral (commonly used for spinal posture assessment), other positions such as arms crossed on chest, and hands on the clavicle have not been investigated by previous published studies. Therefore, our comparisons to other published studies on DIERS reliability and the effects of sitting on spinal shape parameters are limited.

Limitations of the study

Only healthy male students were recruited in the study, and the findings cannot be generalized to females and elderly populations with or without musculoskeletal disorders. Moreover, changing feet/leg position in the frontal plane was not used in our study as it might not be important while looking at standing spinal postural measurements. However, internal or external rotation of the hip may influence pelvic parameters to a certain extent. Moreover, an increased number of t-tests used to determine the effects of prolonged sitting on spinal shape parameters might increase the chances of Type 1 error.

Future recommendations

Further studies should focus on having a larger sample size including participants of both sexes, different age groups and BMI levels, different physical activity levels, and those with or without spinal postural abnormalities. There is a need to identify reference values of spinal shape parameters for different age groups and both sexes as well as to ascertain the effect of certain positions and treatment effects on different conditions such as scoliosis and kyphosis. Future studies would need to substantiate between-day reliability of DIERS formetric measurements, and the effects of prolonged sitting on altered spinal posture and associated long-term consequences.

CONCLUSIONS

The current study found that for between-day reliability, of the 11 spinal parameters analyzed, trunk and pelvic imbalance measures (such as pelvic obliquity, coronal imbalance, pelvic torsion, and vertebral rotation [amplitude]) showed low between-day reliability as compared to other parameters. Further, standing neutral and hands-on the clavicle showed low between-day reliability compared to other positions. This study also showed a significant difference between pre- and post-sitting for 2 hours on specific spinal parameters except pelvic imbalance (pelvic obliquity and torsion) and spinal deviation (vertebral rotation) parameters.

In summary, most spine shape parameters (localization, distance, and spine curve measurements) showed acceptable between-day reliability for most standing positions. However, certain trunk/pelvic imbalance and spinal deviation measures were found less reliable. Our preliminary findings revealed that most spine shape parameters showed a statistically significant difference following prolonged sitting for 2 hours for almost all standing positions, which warrants further investigation.

ETHICS

The University of Sharjah's Research Ethics Committee reviewed and approved the study (REC-20-02-05-03-S).

CONTRIBUTIONS

AA conceived and designed the study and led the writing of the manuscript; AA, AMJ, SFM, RMM, LAA, MKA and MA carried out the participant recruitment, data collection and follow-up of clients; All authors contributed to study design and writing the manuscript; AA curated the data, interpreted the findings, critically appraised the intellectual content, and drafted the manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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