Validation of a novel spinal posture monitor: comparison with digital videofluoroscopy

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Abstract

Purpose A novel, minimally invasive posture monitor which can monitor lumbar postures outside the laboratory has demonstrated excellent reliability, as well as concurrent validity compared to a surface marker-based motion analysis system. However, it is unclear if this device reflects underlying vertebral motion.

Methods Twelve participants performed full range sagittal plane lumbo-pelvic movements during sitting and standing. Their posture was measured simultaneously using both this device (BodyGuard™) and digital videofluoroscopy.

Results Strong correlations were observed between the two methods (all $r_s > 0.88$). Similarly, the coefficients of determination were high (all $r^2 > 0.78$). The maximum mean difference between the measures was located in the mid-range of motion and was approximately 3.4° in sitting and 3.9° in standing.

Conclusion The BodyGuard™ appears to be a valid method for analysing vertebral motion in the sagittal plane and is a promising tool for long-term monitoring of spinal postures in laboratory and clinical settings in people with low back pain.

Keywords Low back pain · Posture · Validity · Fluoroscopy · Ergonomics

Introduction

Low back pain (LBP) is a very common and costly musculoskeletal disorder [1]. Different contributing factors in LBP have been proposed, including provocative spinal postures and movement patterns [2]. While mechanical loads due to provocative postures and movement patterns do not cause LBP in isolation [3, 4], assuming non-neutral postures may increase the risk of developing LBP [5]. Furthermore, static postures and dynamic tasks such as bending or lifting are common aggravating factors for LBP subjects [2]. As a result, avoiding provocative spinal postures is commonly advocated for LBP [5].

The most common method of analysing spinal posture is using surface markers in laboratories [2]. While such systems may not have the accuracy of radiographic imaging [6], they involve no irradiation. Unfortunately, these systems are costly, complex, time-consuming and cannot be easily used in “real-world” settings. Many of these systems are also limited by their inability to provide instantaneous postural feedback while LBP subjects perform daily tasks. This is significant considering the role reduced postural awareness may play in LBP [7].

Many studies examining the role of posture in LBP have simply considered the duration or frequency the posture is adopted, rather than actual spinal posture [3, 4]. Similarly, the measurement techniques used in previous occupational research have been constrained by technological limitations. Digital photography and video analysis are commonly used in ergonomic research as a relatively cheap and non-invasive option [8, 9]. However, they may not be

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sufficiently sensitive to detect subtle changes in spinal posture. To better evaluate the relationship between posture and LBP, minimally invasive methods of monitoring posture and motion of the lumbo-pelvic region during occupational and daily tasks outside the laboratory are required.

Several portable, minimally invasive methods of analysing posture in “real-world” settings have recently been developed. Spinal posture analysis is now possible using devices based on accelerometers [10], inclinometers [11], gyroscopes [12], fibre-optics [13], strain gauges and/or optical sensors [14, 15] and ultrasound [16]. Despite their potential, some devices are relatively large and cannot be concealed easily [14], or can only be used under supervision [17]. While the reliability and/or validity of some of these devices has been investigated [10, 14, 16], this is not the case with all devices [11, 15, 17]. Other devices can provide a snapshot of static spinal posture, but cannot analyse dynamic posture or provide postural feedback [18, 19].

The “BodyGuard™” (Sels Instruments, Belgium) monitors spinal sagittal plane posture using a strain gauge. It has no cumbersome cables, facilitating more normal movement in a variety of tasks both inside and outside the laboratory. Unlike many portable monitors which can either monitor posture or provide postural feedback [11, 15, 17, 20], it can both monitor posture and provide immediate real-time postural biofeedback (audio or vibratory). The between-day and inter-rater reliability of the device in measuring lumbo-pelvic posture is excellent [21]. Furthermore, it has recently been validated as a measure of lumbo-pelvic posture and movement in a range of seated and standing functional tasks [22]. However, to facilitate analysis of complex movement tasks, the study [22] simply compared the BodyGuard™ to a surface marker-based system (CODA™). Therefore, it is unclear if the BodyGuard™ truly reflects underlying vertebral alignment and motion. This study aimed to investigate the validity of the BodyGuard™ device as a measure of underlying vertebral alignment and motion, using digital videofluoroscopy as the reference standard.

Materials and methods

Participants

Twelve participants (six female) were recruited from within a university community. Participants’ mean (SD) age was 22(1) years, height was 176(10) cm, mass was 71(11) kg and body mass index was 23(3) kg/m². Participants with current or previous LBP, previous spinal surgery, serious health problems, who were aged <18 years or who were pregnant were excluded. All participants provided written informed consent. Ethical approval was obtained from the local university research ethics committee.

Instrumentation

The BodyGuard™ consists of a lightweight battery-powered processing unit and a strain gauge, which communicates via a proprietary wireless protocol with a computer (Fig. 1a). Posture is expressed as a percentage of strain gauge elongation, so that the degree of flexion/extension is expressed relative to range of motion (ROM), rather than being expressed in degrees. Digital videofluoroscopy (DVF) is a motion X-ray recording of the spine, combining video technology with traditional fluoroscopy. DVF images at 25 Hz were obtained with a Philips Diagnost Super 80CP system (1,024 × 1,024 image resolution) (Philips Medical Systems, Best, The Netherlands). The image intensifier was positioned to the side of the participant’s lumbo-pelvic region, so that the field of view could capture all lumbo-pelvic motion performed. The radiograph beam field of the videofluoroscopy unit was collimated to obtain optimal sharpness of the image. The exposure parameters were 80 kV. The average fluoroscopy time per participant was approximately 20 s with a mean dose–area product (DAP) of 28 dGy/cm². The estimated effective dose for the whole procedure was 0.22 mSv, which is lower than the effective dose of a single plain radiograph of the lumbar spine (0.39 mSv). Radiation parameters were reviewed with a radiation physicist before the study to ensure that radiation exposure was minimised. Pilot testing ($n = 4$) confirmed that the best images of the lumbo-pelvic region were obtained by performing lumbo-pelvic flexion/extension as a pelvic tilt. Otherwise, image quality deteriorated as participant movement during forward bending shifted them out of the centre of the image intensifier’s field of view. Although some previous studies [23] have overcome this issue by stabilising the pelvis within the DVF unit while participants perform spinal flexion/extension, this may not reflect natural spinal motion, especially at the lower lumbar levels.

Calibration

A 6-cm BodyGuard™ strain gauge was positioned using adhesive tape over the spinous processes of L3 and S2, located by manual palpation (Fig. 1a). Calibration of the BodyGuard™ relative to maximum ROM was then performed in both sitting and standing. For sitting, the participants sat in the DVF unit (no back support) with their feet supported, and their knees and hips flexed to 90°. Participants performed flexion and extension of the lower lumbar spine by performing a pelvic tilt. After three practice attempts, participants sustained full anterior pelvic tilt for 3 s, and this was set as 0 % ROM. Maximum lumbar flexion was set as 100 % ROM by sustaining full posterior pelvic tilt in a similar manner. For standing,

Fig. 1 **a** Subject in sitting with the BodyGuard™ posture monitor positioned using adhesive tape over the lower lumbar spine, at the levels of L3 and S2. **b** Subject performing full anterior and posterior pelvic tilt in sitting and standing. This movement was used for initial calibration of full range of movement, and then as the actual movement during testing

participants stood upright in the DVF, barefoot with their knees extended. Similar to sitting, participants performed a pelvic tilting manoeuvre in standing to calibrate the lower lumbar position relative to standing ROM (Fig. 1b).

Experimental protocol

First, participants were asked to perform a maximal pelvic tilt (from anterior to posterior) in sitting, as performed in the calibration procedure. Two trials were performed, whereby movement of the spine was captured in a synchronised manner by the BodyGuard™ (20 Hz) and the DVF (25 Hz). Secondly, participants were asked to perform a similar procedure for maximal pelvic tilt in standing. Data were averaged for the two trials in each position.

Data analysis

Data of 23 sitting and 24 standing trials were analysed. One dataset (sitting) was lost because of a software error. Synchronised BodyGuard™ and DVF data were analysed at 5 Hz. DVF data were analysed semi-automatically. Anatomical landmarks (corners of the vertebrae) were first manually marked and digitised on the DVF footage. Subsequently, the digitised data were analysed using an in-house custom-made software program. Lumbar lordosis was measured by calculating the angle between lines perpendicular to the midline of L3 and the cranial side of the

sacrum (Fig. 2). The reliability of this approach was assessed for two different raters using a single pilot data set. Both intra-rater and inter-rater intra-class correlation coefficients (ICC) were >0.97 , while the mean difference between all measurements reached a maximum of 5.4° . This demonstrates a very good level of reliability, similar to previous DVF studies [24].

Since BodyGuard™ data were expressed as % ROM, DVF data were converted to % ROM, relative to the calibration movements similar to BodyGuard™ data. Data were non-normally distributed (Shapiro–Wilks, $p < 0.05$). The correlation between BodyGuard™ data and DVF data was assessed separately for sitting and standing across all subjects using Spearman's rank correlation coefficient (r_s), and the coefficient of determination (r^2). To accept the validity of the BodyGuard™ device, it must demonstrate a strong correlation ($r_s > 0.8$) [25]. Furthermore, to assess the effect of position within the ROM on the relationship between the BodyGuard™ and DVF, BodyGuard™ data were segmented into bands of 10 % of ROM based on DVF % ROM values for each measurement. Average BodyGuard™ values of each 10 % band were calculated and the mean difference between BodyGuard™ and DVF data was assessed. When assessing the mean difference from DVF values, differences $>5^\circ$ (approximately, 13 % of sitting ROM and 17 % of standing ROM) were considered large errors, consistent with another validation study [10]. An independent t test examined for significant differences between genders, and a paired t test compared sitting and standing ROM. Data were analysed using SPSS 15.0.

Fig. 2 Illustration of the method used to calculate the lumbo-pelvic angle on digital videofluoroscopy, including marking corners of the vertebrae, and the use of *perpendicular lines* (solid) to calculate the complementary angle (dotted line)

Results

Since the calibration procedures differed, results for sitting and standing are presented separately. Strong correlations were observed in both sitting ($r_s = 0.94$) and standing ($r_s = 0.88$). Similarly, coefficients of determination were high for sitting ($r^2 = 0.88$) and standing ($r^2 = 0.78$). The mean differences (as % ROM) between DVF and BodyGuard™ values throughout the full ROM are displayed in Fig. 3. The maximum mean difference was 9.1 % in sitting, and 12.9 % in standing, and occurred near the mid-range of movement. A representative scatter plot of values for one female subject during standing is illustrated in Fig. 4, where the slight underestimation of flexion by the BodyGuard™ can be seen in mid-range. When converting these percentages into angles, based on mean ROM in each test position, these maximum mean differences were 3.4° and 3.9° , in sitting and standing, respectively. The ROM (mean + SD) in sitting ($37.3 + 11.2^\circ$) was significantly larger than in standing ($30.2 + 10.4^\circ$) ($p = 0.03$). There was no statistically significant difference in the ROM

Fig. 3 Mean differences between digital videofluoroscopy and BodyGuard™ measurements in sitting and standing through every 10 % of range of motion (ROM). 0 % = maximum lower lumbar extension; 100 % = maximum lower lumbar flexion

Fig. 4 A representative scatter plot comparing BodyGuard™ (BG) and digital videofluoroscopy (DVF) during standing measurements, with values expressed as a percentage of range of motion (% ROM)

(mean + SD) between male ($32.8 + 11.1^\circ$) and female ($34.5 + 11.5^\circ$) participants ($p = 0.611$).

Discussion

This study examined the validity of a novel spinal posture monitoring device (BodyGuard™) by comparing lumbo-pelvic posture during sagittal plane pelvic tilting with simultaneous DVF measurements. Overall, the two methods displayed strong correlations and high coefficients of determination. Furthermore, the mean differences between the two measurements of lumbo-pelvic posture were not large, particularly approaching end-range motion, suggesting the BodyGuard™ device is a valid measure of underlying lumbo-pelvic vertebral motion. It is noteworthy that these results are very consistent with previous data examining the concurrent validity of this posture monitor during seated and standing functional tasks, although that study [22] simply used a surface marker system for comparison. These two validation studies together suggest that the BodyGuard™ is a valid measure of lumbo-pelvic sagittal plane posture.

Establishing the validity of any spinal posture monitor is critical before it can be recommended for use in clinical

trials. While absolute agreement between any skin-mounted posture monitor and measurement of underlying vertebral posture and motion is unrealistic, these results suggest the validity of the BodyGuard™ device is similar, or indeed superior, to that of other posture monitors [20, 26–28]. Both a small flexible electrogoniometer (Biometrics™) and a larger electrogoniometer (OSI CA-6000) have demonstrated similar mean differences, but poorer correlations, compared to X-ray measurement of lumbar posture and/or ROM [20, 26, 29]. Similarly, a monitor which combines electrogoniometry with pelvic inclinometry and chair-backrest contact data (Rachimetre™) and another method of analysing static spinal posture (Spinal Mouse™) were strongly correlated to overall lumbar ROM [27, 28], without examining through-range accuracy. Furthermore, many other portable posture monitors [10, 13, 16] have simply been validated against surface marker systems rather than methods such as DVF, X-ray or MRI. It is noteworthy that the validity of the BodyGuard™ device as a measure of lumbar curve is actually superior to the lumbar motion monitor (LMM™), which is commonly used in occupational analysis [6].

When data were partitioned into 10 % intervals of ROM (based on DVF data), there was slightly greater error in mid-range. This was expected, since the BodyGuard™ device was calibrated at end-range flexion and extension. The BodyGuard™ appears to slightly, and consistently, underestimate lumbo-pelvic flexion through range compared to the DVF, particularly in standing. However, the maximum difference was still only 3.4° (9.1 % ROM) and 3.9° (12.9 % ROM) in sitting and standing, respectively. This is in line with the error reported by other skin-mounted posture monitors [20].

The ROM obtained in sitting was significantly larger than in standing, possibly due to greater ease facilitating pelvic motion in sitting due to direct contact with the stool. The ROM obtained is broadly in line with data on segmental vertebral motion from L3 to S1 [30].

Implications

The results of this study, when combined with previous studies [21, 22], suggest that the BodyGuard™ device is a reliable and valid means of measuring lumbo-pelvic sagittal plane posture and movement. It is a simple, economical and minimally invasive postural monitoring system that should allow normal movement and function in “real-world” settings. The small size and ease of use of the BodyGuard™ may allow field-based studies to investigate in detail the role of posture and lumbo-pelvic movement patterns in LBP. Further discriminative validity studies are required to determine if the device can discriminate between subgroups of subjects with LBP and matched

controls, similar to existing laboratory-based systems [2]. Modification of posture has been associated with improved clinical outcomes [31], and recent studies demonstrate that provision of postural awareness training may help normalise spinal motion [15], reduce spinal loading [32] during lifting tasks and improve clinical outcomes in both acute and chronic LBP [17, 33]. The potential to provide patients with feedback regarding the control of their lumbo-pelvic movement patterns via the BodyGuard™ requires further clinical investigation.

Limitations

The sample size was small to limit the number of participants exposed to irradiation, but was similar to previous validation studies [29]. The device has only been validated in the sagittal plane, which reflects the way in which the device is used. While the device does not provide an angular value for lumbo-pelvic posture, research indicates that expressing lumbar posture relative to ROM may be very useful [2]. Limiting motion to pelvic tilting may not truly reflect sagittal plane lumbo-pelvic motion during routine daily tasks; however, concurrent validity during complex functional tasks has already been established [22]. In addition, the study has demonstrated that the BodyGuard™ is a valid measure of underlying spinal motion, so that it is unlikely that this differs significantly in forward and backward bending of the trunk. Furthermore, this approach allowed simultaneous measurement of lumbo-pelvic motion, unlike previous research [29]. Similar to all skin-mounted posture monitors, variations in body mass index may affect accuracy. It should also be acknowledged that LBP is a complex biopsychosocial disorder where analysis of multiple factors other than lumbo-pelvic posture and movement patterns is warranted [34].

Conclusion

The BodyGuard™ device provides a valid analysis of lumbo-pelvic motion in the sagittal plane. The minimally invasive nature of the device may be appropriate for use in “real-world” settings outside the laboratory when detailed assessment of lumbo-pelvic posture and motion is required. Future studies on its ability to identify subjects with LBP, and to provide real-time postural feedback in LBP subjects, are indicated.

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Conflict of interest None.

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