The reliability of the CODA motion analysis system for lumbar spine analysis: a pilot study

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ABSTRACT

Background: Low back pain (LBP) is a very common musculoskeletal disorder. Lumbar range of motion (ROM) and posture are parameters which are commonly assessed in LBP research. Reliable methods of measuring lumbar spine ROM and posture are needed. The CODA motion analysis system has several potential advantages over other motion analysis systems; however, its reliability for lumbar spine analysis has not been examined. This study investigated the reliability of the CODA system for measuring lumbar spine sagittal plane ROM and posture.

Methods: Twelve participants were tested by two investigators on two occasions. Ten trials of lumbar ROM and usual sitting posture were performed. The reliability of upper lumbar, lower lumbar, and pelvic sagittal plane motion was assessed using intra-class correlation coefficients (ICC) and Bland and Altman methods, including evaluation of the mean difference and limits of agreement.

Results: Levels of association were very good for ROM, for both intra-rater and inter-rater measurements (all ICC >0.7). However, agreement was more variable, with some lower lumbar and pelvic regions displaying large mean differences and wide limits of agreement. Overall, greater reliability was obtained for the upper lumbar region angles, and for intra-rater comparisons.

Conclusion: Reliability of the CODA system varied from very good to fair, depending on the parameters assessed. While good association was found between most parameters, the level of agreement was only fair to moderate. Recommendations are made to improve the protocol used to assess spinal motion, which may improve reliability.

Keywords: coda, lumbar spine, posture, range of motion, reliability

INTRODUCTION

Low back pain (LBP) is a very common and costly disorder.1,2 It is a complex biopsychosocial disorder, requiring consideration of both biomedical and psychosocial factors.3-5 Two factors commonly studied in quantitative LBP research are lumbar spine range of motion (ROM) and posture.6-8 The overall contribution of these factors in LBP development and/or maintenance of LBP remains controversial.9-11 However, they are widely considered in the assessment of patients with LBP in both research and clinical practice.6,10,12,13

Simple visual observation of ROM and posture is common in clinical practice13, but has poor reliability.14 Other methods including flexible rulers,15,16 inclinometry,12,17-19 electrogoniometry,20,21 digital photography,22,25 and accelerometry,26 have some evidence of reliability, but their sensitivity to detect subtle differences in posture or ROM is unknown. In addition, some of these methods do not facilitate measurement in multiple planes of motion. As a result, analysis of spinal ROM and posture is usually performed using more sensitive, but complex, laboratory-based motion analysis systems.27-29

Many different motion analysis systems are used, with some systems having evidence of their reliability and validity.20-32 However, the reliability analysis used in many of these studies18,23,27 has been criticised,34,35 as the level of association between the data is assessed and no information on the level of agreement between measures is provided. It is recommended that ICC values be complemented with data that examines the level of agreement between measurements, for example using Bland and Altman methods.34,36 This allows interpretation of how closely related the measures are, rather than simply correlating the measures.

The Cartesian Optoelectronic Dynamic Anthropometer (CODA) motion analysis system (Charnwood Dynamics Ltd., Leicestershire UK) uses an infrared active marker system. It has several potential advantages over standard laboratory-based motion analysis systems, as it is fully portable outside the laboratory, facilitates measurement in three dimensions, and requires no calibration. It has good reliability in lower limb gait analysis,37 and has also been used for analysing spinal ROM and posture.38 However, it's reliability for spinal analysis has not yet been established.

Forward bending and sitting are common aggravating factors in LBP3,9 and are commonly analysed in clinical practice and research.3,6,10,39 Therefore, this pilot study analysed these sagittal plane postures to establish the intra-rater and inter-rater reliability of using the CODA motion analysis system to model spinal motion.

METHODS

The local university research ethics committee approved this study.

PARTICIPANTS

Twelve participants (7 females) were recruited from within the university campus. Participants' mean (SD) age was 29.6 (12.1) years, mean weight was 70.5 (13.8) kg, and mean

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height was 1.68 (0.11) meters. Prior to participation written informed consent was obtained. To ensure that participants were capable of reproducing the required movement and posture consistently, participants were excluded if they had previous back or hip pain.

**Experimental setup**
Participants were tested on two occasions 3 to 14 days apart (mean (SD) 4.9 (3.3) days) at the same time of day. Participants sat on a wooden stool, wearing shorts, with their bare feet on the ground, and arms folded across their chest. Two CODAmpx30 cameras were placed at a 45° angle posteriorly to the participants. A spinal marker protocol developed by the manufacturers was used to place the spinal markers. CODA markers were placed using double-sided adhesive tape over T11, L1, and L4 which were identified in a flexed sitting posture with a non-permanent skin marker, which was removed after each testing session. To facilitate future analysis of coronal and transverse plane motion, two markers were placed 2.5cm lateral to the L4 spinous process, which enabled the calculation of a "virtual" marker over the L4 spinous process. To monitor pelvic motion, a pelvic wand (with markers reflecting the position of the ASIS and PSIS attached) was applied using a velcro belt in accordance with previous research. (Figure 1)

**Experience of the raters**
Rater 1 was a 3rd year student physiotherapist, with limited experience in LBP assessment, and very little experience with the CODA system. Rater 2 was a musculoskeletal physiotherapy lecturer with 9 years clinical experience, and with previous experience using the CODA system. Prior to testing, the two raters worked together to practice the testing procedure, including: palpation, marker and pelvic wand application, giving instructions, and data recording, to ensure that the methods used were consistent.

**Test protocol**
Ten trials of each posture and movement were collected at 200Hz. Initially, 10 recordings (five seconds duration) of participants were taken in their usual sitting posture. To achieve this, participants were asked to sit in their usual sitting posture while looking straight ahead. Participants were asked to flex and extend their lumbar spine between each recording. For ROM, 10 recordings (10 seconds duration) were taken of the participant's achieving maximum lumbar flexion by posteriorly tilting the pelvis and extension by anteriorly tilting the pelvis in sitting, while maintaining their shoulders over their hips. Participants received standardised verbal encouragement during ROM testing to facilitate them achieving full ROM. To aid consistency, participants practiced with manual and verbal facilitation in advance. The procedure was performed in the same manner on both test days, by both investigators.

**Calculation of spinal and pelvic angles**
The CODA system uses a laboratory-based coordinate system, and calculates joint angles based on the position of skin markers. The angular resolution of each camera was approximately 0.002°, with a lateral position resolution of 0.1 mm at three meters distance (horizontally & vertically), and a distance resolution of about 0.6mm. Pelvic angles were calculated within the CODA motion software in line with previous research. Lumbar spine angles were calculated separately for the upper lumbar spine and the lower lumbar spine, as research indicates that these regions demonstrate functional independence. Vector angles were created within the CODA motion software to represent upper lumbar and lower lumbar motion. The upper lumbar angle was calculated as the intersection of the vectors between T11-L1 and L1-L4. The lower lumbar angle was calculated as the intersection of the vectors between L1-L4 and L4-S2 (S2 being a virtual marker between both PSIS markers). Additionally, usual sitting posture was expressed as the distance from maximum end-range flexion as there is evidence that this method may be important in discriminating between subjects with and without LBP.

The parameters of interest therefore were;
- Total ROM (degrees)
- Usual sitting posture (degrees, and degrees from end-range flexion)

**Statistical analysis**
Data were analysed using SPSS 15.0. ICC's and their 95% confidence intervals (CI's) values were calculated for the intra-rater and inter-rater measurements, using one-way random and two-way mixed models respectively. To establish the level
TABLE 1
Mean (SD) range of motion for pelvic, upper lumbar and lower lumbar regions (n=12).

<table>
<thead>
<tr>
<th>ROM</th>
<th>Rater 1: Day 1 (°)</th>
<th>Rater 1: Day 2 (°)</th>
<th>Rater 2: Day 2 (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic</td>
<td>33.14 (9.8)</td>
<td>32.15 (9.57)</td>
<td>27.22 (6.26)</td>
</tr>
<tr>
<td>Upper Lumbar</td>
<td>33.26 (4.31)</td>
<td>32.48 (5.43)</td>
<td>31.73 (5.98)</td>
</tr>
<tr>
<td>Lower Lumbar</td>
<td>20.67 (8.09)</td>
<td>19.22 (6.46)</td>
<td>16.94 (8.83)</td>
</tr>
</tbody>
</table>

ROM = range of motion, all measurements in degrees

of agreement between measurements Bland and Altman methods were used, including a calculation of the mean difference (d), 95% CI for the d, standard deviation of the d (SDdiff), and the limits of agreement.

RESULTS
The ROM and posture values obtained for all participants (mean, SD) are displayed in Tables 1 and 2 respectively. The reliability of these measurements are displayed in Table 3.

ROM reliability
Overall there was substantial association$^{42}$ between ROM measurements, both intra-rater and inter-rater (ICC's > 0.7). However, some of the 95% CI's for the ICC's were very wide (Table 3), indicating the ICC values obtained were a less precise estimate. The level of agreement for both intra-rater and inter-rater reliability varied from very good to fair. Upper lumbar agreement was very good for both intra-rater and inter-rater, with values for d being close to zero (0.74° and 0.79°), and an acceptable 95% CI of <6°. For pelvic and lower lumbar regions, intra-rater agreement was good with small values for d (1° and 1.4° respectively), and narrow 95% CI's of 6° and 7° respectively. However the inter-rater agreement for both pelvic and lower lumbar regions was less, with higher values for d (5° and 2°), and wider 95% CI's for d (10° and 8° respectively). Zero lay within the 95% CI for all but 1 of the ROM measurements (inter-rater pelvic), indicating that a systematic bias may have occurred during the assessment of pelvic movement only.

Posture reliability
Overall the association between usual sitting posture measurements varied from poor to excellent (ICC's range = 0.27-0.97). Upper lumbar posture measurements obtained excellent ICC values (ICC all >0.89), with narrow CI's, indicating a precise estimate and a strong association. ICC values for low lumbar and pelvic posture measurements however varied from poor to excellent (ICC = 0.27-0.93). While many of these ICC values appear good in isolation, the wide CI's indicate the estimate is imprecise, such that the overall association is moderate at best. The level of agreement for both intra-rater and inter-rater for upper lumbar posture measurements was very good, with d values close to zero (approximately 1°), and the 95% CI <6°. For pelvic and lower lumbar regions, the level of agreement was lower.

TABLE 2
Mean (SD) angle during usual sitting for pelvic, upper lumbar and lower lumbar regions (n=12).

<table>
<thead>
<tr>
<th>Usual Sitting Posture</th>
<th>Rater 1: Day 1 (°)</th>
<th>Rater 1: Day 2 (°)</th>
<th>Rater 2: Day 2 (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvic</td>
<td>-18.66 (5.98)</td>
<td>-18.46 (4.47)</td>
<td>-17.50 (6.87)</td>
</tr>
<tr>
<td>Upper Lumbar</td>
<td>-6.99 (10.98)</td>
<td>-5.48 (10.19)</td>
<td>-5.95 (9.99)</td>
</tr>
<tr>
<td>Lower Lumbar</td>
<td>-2.55 (4.57)</td>
<td>-4.29 (7.35)</td>
<td>-3.97 (5.69)</td>
</tr>
<tr>
<td>Pelvic*</td>
<td>13.62 (7.17)</td>
<td>13.73 (5.62)</td>
<td>11.25 (5.99)</td>
</tr>
<tr>
<td>Upper Lumbar*</td>
<td>-12.99 (6.85)</td>
<td>-12.17 (7.19)</td>
<td>-11.12 (6.65)</td>
</tr>
<tr>
<td>Lower Lumbar*</td>
<td>-3.48 (3.84)</td>
<td>-3.36 (4.67)</td>
<td>-2.55 (3.53)</td>
</tr>
</tbody>
</table>

*Indicates sitting posture angle when calculated relative to end-range flexion ROM.
All measurements in degrees
Negative values indicate posterior tilt in the pelvic region, and extension in the lumbar region.
because even though the values for $d$ are small (all $<2.5°$), the 95% CI's are wider (range between 4°-10°), indicating a less precise estimate. It is noteworthy that the reliability of usual sitting posture was improved when posture was expressed relative to total ROM, with better ICC values ($ICC = 0.57$-$0.93$), and smaller values for $d$. Zero lay within the 95% CI for all posture measurements, indicating that no systematic bias occurred in the measurements obtained.

**DISCUSSION**

The reliability of the CODA system in measuring sagittal plane ROM and posture in sitting varied from fair to very good. ICC values suggest the level of association was good, as 15/18 measurements had an ICC value $>0.7$. Chin$^{16}$ suggested ICC values above 0.6 are useful, while Landis and Koch$^{42}$ stated that ICC’s between 0.6-0.8 are substantial. However, some parameters, particularly inter-rater pelvic posture, displayed poorer agreement, indicating only a moderate level of reliability for these particular parameters. In general, greater reliability was obtained for the upper lumbar region, and for intra-rater comparisons.

The reliability of many other motion analysis systems used in the measurement of lumbar ROM has been investigated. A device incorporating potentiometers (OSI CA6000$^{TM}$) has been found to be reliable for measuring ROM, based on ICC values consistently being $>0.8$ for intra-rater and inter-rater reliability.$^{3,13}$ Studies of an electromagnetic system (Fastak$^{TM}$) obtained ICC values similar to those obtained in this current study,$^{10,13}$ and another electromagnetic system (Flock of Birds$^{TM}$) displayed good reliability of measurements of lumbo-pelvic motion during a rowing task.$^{15}$ A device based on inclinometry (“Back ROM Device”) was also found to have good association between measurements of sagittal plane lumbar ROM ($ICC = 0.67$-$0.78$).$^{46}$ Both Steer et al$^{45}$ and Madson et al$^{46}$ demonstrated the mean difference between measurements was low with both the “Flock of Birds” system, and the “Back ROM Device”, providing further knowledge regarding agreement between the measures, similar to this current study. Finally, digital photographs display good association$^{24}$ for lumbar ROM, although the degree of agreement is unclear.

In contrast, less research has been performed on the reliability of motion analysis systems for measurement of static postures. Research has mainly focused on standing posture, with most demonstrating very good reliability for measurement of standing lumbar posture. For example, Ng et al$^{18}$ obtained an ICC of 0.95 for the measurement of standing sagittal plane lumbar posture using inclinometry. The OSI CA6000$^{TM}$ system has also demonstrated excellent reliability (ICC=0.96, error measurements of $<2.5°$) for measurement of standing sagittal posture.
plane posture.29,47 The Vicon™ system has commonly been used in research involving LBP,49 and has evidence of good association between measurements for pelvic and lumbar angle, with ICC values >0.78 for test-retest reliability in standing.49 Similarly, another device (Metrecom™) has shown evidence of good test-retest reliability (ICC all >0.88) for analysis of standing lumbar curvature.29 It appears that digital photographs are less reliable for standing postures29 with poor association and wide variation. In contrast to standing posture, very little data is available on the reliability of seated lumbar posture or ROM. Pownall et al,23 examining the consistency of seated posture using digital photographs, obtained an ICC value of 0.66 for seated lumbar posture, which is lower than this current study. It is difficult to compare the reliability of the CODA system with these other systems for measuring static posture, as the differences may be related to the position (sitting versus standing), rather than the system itself. For both ROM and posture however, greater association and agreement between measurements is required for the CODA system to be recommended in multi-centre LBP clinical trials.

Based on previous research it may be perceived that other systems are more reliable than the CODA system for measuring lumbar ROM and posture. However, it is important to consider the limitations of reliability studies which simply correlate measurements to estimate reliability, so the true level of agreement for these devices is unclear.43,45 In the current study, ICC values alone give a misleading impression on the reliability of measurements. It is clear that for some measures in the current study there was only a moderate level of agreement between tests, and thus less reliability. This was particularly the case for inter-rater comparisons, and for the lower lumbar and pelvic regions. For example, the level of association between the measurements for inter-rater pelvic ROM was very good (ICC=0.87), yet χ was considered large at 5°. Ideally, χ should be small and close to zero, however the clinical acceptability of this difference is based on an overall interpretation of the data. Yousaf et al10 suggested a difference of 4°-7° between measurements was clinically acceptable, which would imply the differences obtained in the current study are acceptable. However, the authors of the current study suggest that the high value for χ (5°) and the 95% CI width of approximately 10° in the context of a total pelvic ROM of approximately 30° is unacceptably high. In contrast, all χ values for the upper lumbar region were <2°, within a similar total ROM of approximately 30°. These upper lumbar values for agreement are considered to be at an acceptable level, which is supported by previous researchers that indicated a difference in the upper lumbar region of 4-7° may be present in the sitting posture of subjects with LBP.6

Limitations
The sample size, although similar to previous reliability studies,18,23,32 is small. A sample size of greater than 50 is recommended26 to accurately interpret the limits of agreement, and allow detailed assessment of clinical acceptability. Although the CODA system allows 3-D motion analysis, reliability was only established for the sagittal plane in sitting. Clearly analysis of other planes of motion, in other positions, is required. Similar to all motion analysis systems which involve placement of markers on the skin, marker displacement due to skin movement is a potential source of error. Errors of palpation are a risk in spinal marker placement; however every effort was made to ensure consistency of palpation technique between raters. Inconsistent movement or postures by participants may explain some of the variation; however this was minimised by giving clear instructions and manual facilitation in advance, along with time to practice each procedure. Some previous studies have used semi-permanent skin marking to ensure that spinal markers were applied at the same level at the 2nd test session.29 Using such an approach could have improved reliability; however this would not reflect the true risk of error in spinal marker placement in multi-centre trials. The lack of an existing, established protocol for placement of CODA spinal markers necessitated the development of an untested marker protocol. The values for ROM and posture are not comparable to any other normative data as past studies consistently demonstrate that even when motion analysis devices are reliable, their values do not agree.32,50,51 On inspecting the results, it is clear that the reliability was best for the upper lumbar region. A potential reason for poorer reliability in the other regions is the use of pelvic wands to monitor pelvic and lower lumbar motion, rather than direct skin markers. During testing, both testers noted difficulty obtaining a consistent, secure fixation of the pelvic wand, possibly contributing to the particularly poor reliability data for inter-rater pelvic posture compared to other measurements. The authors intend to develop a new marker protocol involving direct placement of skin markers on the pelvis. The fact that the reliability of usual sitting posture was much better when expressed relative to end-range flexion also supports this contention, since it is likely this helped overcome any systematic bias in placement of the pelvic wands. Interestingly, previous studies using CODA suggest that pelvic measurements are also the least reliable in gait analysis. Despite these limitations, it is important to consider that this was the first study to examine the reliability of this motion analysis system for use on the lumbar spine. It is common for motion analysis systems to undergo refinement after initial piloting and reliability studies.33 In addition, unlike many studies examining the reliability of spinal motion analysis systems which simply examined the level of association between the data obtained,31,33 this study considered reliability more comprehensively by including Bland and Altman methods. Finally, to reflect recent research indicating functional independence between the upper and lower lumbar regions,5,41 these regions were considered separately instead of analysing the entire lumbar spine together.

Recommendations
The good reliability of upper lumbar values in this study demonstrates that CODA has the potential to be a useful tool in future LBP research. However further modification of the current protocol, particularly for the lower lumbar and pelvic regions, may be required in order to increase reliability. This will involve using direct skin markers on the pelvis and sacrum. Once the reliability of this new marker protocol is established, in both LBP and pain-free subjects, CODA may be an appropriate tool for LBP research considering the advantage it
has over some other motion analysis systems in that it is fully portable outside the laboratory, facilitates measurement in three dimensions, and requires no calibration. Thereafter validation against another motion analysis system, or a suitable reference standard e.g. X-ray or MRI, may be indicated before progressing to use in large clinical trials, similar to the approach used with other motion analysis systems.31,32,52,53

CONCLUSION
Reliability of the CODA system varied from fair to very good overall, depending on the parameters and testers involved. Measurements of the upper lumbar region were found to be more reliable than the lower lumbar and pelvic regions. While good levels of association were found between most parameters and testers involved, lower levels of agreement for some parameters indicated a moderate level of reliability overall. This highlights the need for future research to consider both measures of association and agreement in reliability studies. Further research using direct skin marker placement over the pelvis and sacrum may further improve the reliability of the system for spinal analysis.

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