Dynamic control of the lumbopelvic complex; lack of reliability of established test procedures

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Abstract Impairment of the dynamic control of the lumbopelvic complex in LBP has gained increased focus both clinically and experimentally. The objectives of this study were to determine the reliability of inclinometry as a measure of dynamic lumbopelvic control. Lumbopelvic reposition accuracy during pelvic tilts was measured in 39 healthy subjects using an inclinometer attached to the skin at S2 level. The reposition accuracy was measured in sitting, standing and supported standing. Tests were performed three times with a 20 min recess between tests. Only data from the last two test sequences were used in order to account for learning effects. Intraclass correlation coefficients were low for the sitting (0.54) and supported standing positions (0.36). In the standing position, a significant difference between test and retest was observed ($P = 0.003$) and further reliability analysis was therefore abandoned. It is concluded that inclinometry is not reliable for measuring the dynamic lumbopelvic control in any of the test positions and prior work utilising inclinometry to evaluate dynamic lumbopelvic control should be interpreted with caution.

Keywords Low back pain · Proprioception · Reliability · Inclination · Diagnostics

Introduction

The lack of specific diagnosis in low back pain (LBP) makes the therapeutic approach difficult [32], and at least partially, the absence of specific objective diagnostic measures is responsible for the shortcomings in identifying treatments that are convincingly more effective than others.

Impairment of the dynamic control of the lumbopelvic complex in LBP has gained increased focus, and various methods of sensory-motor evaluation are currently applied both experimentally and clinically as a diagnostic tool and for treatment response evaluation [10, 14, 21, 22, 28, 29]. However, there is no cause-effect link established between this concept and clinical low back pain.

The importance of stabilisation of a joint in its neutral zone has been demonstrated [28, 29], and intersegmental instability has been proposed as a possible contributing factor in the development of LBP [14, 15, 20, 21]. An optimal motor control is considered important in order to maintain the functional and structural integrity of the lumbar region [10, 21, 22]. Deficits in the dynamic control of the lumbopelvic complex can compromise and affect segmental spinal stability and eventually lead to tissue damage and later chronic pain [13, 33]. Since the lumbopelvic complex is centrally located, it is prone to biomechanical forces from both trunk and limb movements. Appropriate muscle action is considered important to the function of the lumbar spine as an effective ‘force-bridge’ between the lower and upper extremities, as well as force development in the lumbar region itself. The complex anatomy of the lumbopelvic region and the multidimensional demands to the function, impede specific

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structural diagnostics. The functional complexity of the region is a limiting factor and the evidence to support the theory is mostly experimental; the clinical applications of the measurements remain to be shown.

Altered patterns of trunk muscle activation during simple trunk and extremity movements [14, 15, 20, 21], reduced cross sectional areas in the paraspinal muscles [19] and weak relationships between EMG and isometric forces [30] have been reported in individuals with LBP. These results suggest that individuals with LBP have different motor strategies compared to healthy individuals. However, it is unknown if these observations are the result of pain or tissue damage or if they are the cause of LBP.

Several studies have shown that individuals suffering from peripheral joint disorders have impaired joint reposition accuracy [4, 5, 7, 8, 16, 23–25, 35] and that sensory-motor rehabilitation reduces the reposition errors [1–3, 6, 8].

Studies of spinal reposition have reported conflicting results. Gill and Callaghan compared the reposition accuracy of healthy and LBP subjects and found that LBP patients showed greater reposition errors [18]. Parkhurst found weak correlations between low back injuries and spinal reposition errors [31]. Newcomer found no significant difference in spinal reposition accuracy between LBP and control subjects [26]. Finally, Brumagne concluded that LBP patients have a significantly lower repositioning accuracy than that of healthy subjects [11, 12]. In addition Brumagne et al. performed tests of reproducibility of their assessment method [9, 10]. In these studies, inclinometers were applied during pelvic tilts. Inclinometers are advantageous in clinical settings as they provide objective quantitative information, are easy to apply and available at low cost. The method was reported to be moderately reliable in a group of healthy subjects [9, 10] and was later applied in experimental studies on LBP patients [12]. However, the statistical evaluation of the reliability was not optimal and repeated assessments of the reliability are needed.

If dynamic stability is impaired in low back pain, tests aiming at discriminating patients from the population should be able to test the lumbopelvic position sense isolated in order to be meaningful. For example, significant differences between patients and healthy subjects was only found, when proprioceptive input from the lower limbs was reduced by testing the four-point kneeling position [27]. A criterion for the clinical validity of a method is its ability to distinguish between normality and pathology. Another criterion for evaluating the validity is its reproducibility. This implies that the method should prove reliable in both healthy and

subjects with pathology. Consequently, it was the purpose of this study to repeat the reliability assessment of inclinometry to evaluate the lumbopelvic reposition accuracy in healthy subjects during pelvic tilts. Additionally, the effects of three different postures on the reliability of the tests were evaluated.

Materials and methods

Study design

The study was designed as a test–retest study in which all participating subjects followed a standardised protocol including assessment of the lumbopelvic reposition accuracy in sitting (SIT) and standing (STAND). A randomly selected subgroup completed an additional third test—supported standing (S-STAND). All tests were repeated three times with 20 min recess between tests.

Subjects

Thirty-nine healthy individuals (23 women and 16 men) with ages between 24 and 36 years (mean 27.2, SD 2.8) were invited to participate in the study after signing informed consents. Criteria of exclusion were episodes of LBP within a year from the test, back surgery, a history of inner ear infection and/or neurological, rheumatologic or orthopaedic conditions in the back and/or lower extremities.

The subgroup that performed the additional test (S-STAND) consisted of 11 subjects (6 women and 5 men, mean age 28.8, SD 3.22 years), who were randomly selected from the 39 included subjects. The demography of the subjects is presented in Table 1.

Instrumentation

Pelvic tilts were measured using a piezoresistant electronic lightweight (30 g) accelerometer (Mega

Table 1 Demography of the participating subjects. The tests performed in sitting (SIT) and standing (STAND) was done on the complete sample. A subgroup was extracted for the test in supported standing (S-STAND)

	Complete Sample (SIT and STAND) <i>n</i> = 39		Subgroup (S-STAND) <i>n</i> = 11	
	Mean	SD	Mean	SD
Age (years)	27	2.8	28.8	3.2
Weight (kg)	71.1	12.3	70.8	12.9
Height (cm)	177.1	8.8	177.4	8.4

Electronics Ltd., Finland) attached to the skin over the spinous process of S2 with double-sided tape. The accelerometer measures the static component of the gravitational acceleration and functions as an inclinometer. The device has a precision of at least $1/100^\circ$. Care was taken to ensure that the sensing axis was aligned orthogonal to the axis of pelvic tilt and thereby measuring the relative inclination angle of the pelvis in space. Inclinations were sampled at 1,000 Hz using an A/D converter (National Instruments Inc.) connected to a PC.

Preparation procedures

The same examiner prepared, instructed and tested each and every subject. The subjects were instructed on how to carry out a pelvic tilt before initiating the tests. To eliminate visual input during tests, the subjects were blindfolded and tactile information was minimised by only allowing the subjects to wear loose fitting shorts. The subjects were instructed to maintain a natural upright posture during tests.

In the standing test (STAND), the subjects stood unsupported in their natural relaxed posture. In the sitting test (SIT), the subjects sat on a bench without backrest. The height of the bench was adjusted so that the feet did not touch the ground. In the supported standing (S-STAND) the subjects were standing in a walking frame with the wheels removed and adjustable elbow support height to support the forearms. To secure the same test position in test and retest, the position of the feet (STAND and S-STAND), thighs (SIT) and the height of the support (S-STAND) were marked and noted. Illustrations of the test positions are given in Fig. 1.

Test procedures

In all tests, ten maximal pelvic tilts were performed in both anterior and posterior directions as a warm-up procedure. Maximal range of motion (ROM) was recorded. Subsequently, the test leader verbally guided the subjects to a (pseudo) random target position, and the subjects were instructed to hold this position for 5 s while the inclination was measured. The subjects were asked to remember this position for subsequent repositioning. After measuring the target position, the subjects returned the pelvis to its natural position. Five seconds later, subjects were asked to reproduce the target position. Once the subjects believed that the position was reproduced, they informed the test leader and the position was held and measured in a 5 s period (estimated position). If accessory movements of other body parts occurred (e.g., if knee joint movements or flexion of the thoracic spine), the measurement was aborted and the procedure re-started. The inclination signal was low-pass filtered at 50 Hz and data from 1 to 1½ s (500 samples) of the 5 s (5,000 samples) were averaged in order to yield an inclination angle.

The procedure was repeated six times for each test—three in anterior and three in posterior tilts. The test order was the same for all subjects and alternated between anterior and posterior tilts with anterior tilt as the initial movement. Thus, six targets, and estimated positions were obtained and absolute error (AE) was calculated as the absolute difference between target and estimated position, ignoring the direction of the error. An average of the six AEs were calculated and used as an expression of lumbopelvic reposition accuracy.

Fig. 1 Illustration of the three positions and the mounted inclinometer used to test reliability of joint repositioning during pelvic tilts. **a** Sitting position (SIT). **b** Standing position (STAND). **c** Supported standing position (S-STAND)

To avoid the target position being in the end range of the subjects' range of motion, the test leader inspected the warm-up tilts and thus had a visual impression of the subjects' range of motion and attempted to place the (pseudo) random target position in the mid-range of motion. This procedure was chosen as the ROM measurements were not available online during tests.

For all subjects, the test order was STAND, SIT and S-STAND (subgroup only). Tests in all three positions were completed before the 20 min recess between test and retests.

In an attempt to minimize any learning effect only data from the last two test sequences were analysed.

Statistical analysis

Test and retest values were tested for any significant differences using a paired *t*-test. The level of significance was set to 5% ($P = 0.05$). If any significant differences were observed, further reliability analysis was abandoned.

To assess the relative reliability ICC(2.1) was used. ICC is a valid measure of reliability only if the differences between tests are uncorrelated to the size of the measured values (homoscedastic data). Pearson's correlation coefficient (r) between the absolute test–retest differences and the individual test–retest mean values were calculated and tested against the null-hypothesis ($r = 0$) for each parameter in order to reveal any heteroscedasticity in the data. In case of heteroscedasticity, ICC values may be misleading. A lower-limit 95% confidence interval was calculated for all ICC estimates.

To assess absolute reliability, measurement errors (ME) were calculated as the square root of the Error Mean Square values obtained from the two-way ANOVA results table used in the ICC calculations.

All statistics were calculated using SPSS version 12 for Windows.

Results

A typical example of the distribution of target positions within the ROM is presented in Fig. 2.

The sitting position (SIT)

The mean ROM was 29.4° (SD 9.1°) and 29.7° (SD 9.9°) for test and retest respectively (Table 2). The mean difference in AE between test and retest was 0.00° (SD 0.53° , 95% CI -0.2° : 0.2°). No significant

difference was found between the tests ($P = 0.99$) and no evidence of heteroscedasticity ($r = 0.27$; $P = 0.11$) was found. The ICC(2.1) was 0.54 (95% CI low 0.27) and the ME was 0.38° . The results are shown in Tables 3 and 4 and illustrated in Fig. 3 left panel.

The standing position (STAND)

The mean ROM was 22.0° (SD 7.6°) and 20.1° (SD 7.2°) for test and retest respectively (Table 2). The mean difference in AE between test and retest was 0.29° (SD 0.58° , 95% CI 0.1° : 0.5°). A significant difference ($P = 0.003$) was found between the test and retest in the standing position and further reliability analysis was abandoned. The results are shown in Tables 3 and 4 and illustrated in Fig. 3 centre panel.

Supported standing (S-STAND)

The mean ROM was 20.0° (SD 7.7°) and 20.2° (SD 8.5°) for test and retest respectively (Table 2). The mean difference in AE between test and retest was 0.08° (SD 0.33° , 95% CI -0.1° : 0.3°). No significant difference was found between the tests ($P = 0.44$) but a tendency towards heteroscedasticity ($r = 0.61$; $P = 0.07$) was found. The ICC(2.1) was 0.36 (95% CI low: -0.28) and the ME was 0.23° . The results are shown in Tables 3 and 4 and illustrated in Fig. 3 right panel.

Fig. 2 A representative example of distribution of the target positions (+) within the Range of Motion during a pelvic tilt. Note that three positions were distributed in anterior tilt and three in posterior tilt. The angular values represent the absolute inclination in space relative to gravity (90° represent vertical position of the inclinometer). The central line indicate the comfortable neutral position ($\approx 95^\circ$) of this subject

Table 2 Average range of motion (ROM), standard deviations (SD), 95% confidence intervals and *P*-values from *t*-tests for test retest and test–retest differences in sitting (SIT), standing (STAND) and supported standing (S-STAND)

Range of motion (ROM)	Test		Retest		Test–retest difference			
	Mean	SD	Mean	SD	Mean	SD	95% CI	<i>P</i>
SIT (<i>n</i> = 39)	29.4	9.1	29.7	9.9	−0.3	6.0	−2.1:1.5	0.77
STAND (<i>n</i> = 39)	22.0	7.6	20.1	7.2	1.9	5.0	0.4:3.5	0.02
S-STAND (<i>n</i> = 11)	20.0	7.7	20.2	8.5	−0.2	3.0	−2.0:1.6	0.81

Table 3 Average absolute errors, standard deviations (SD), 95% confidence intervals and *P*-values from *t*-tests for test retest and test–retest differences in sitting (SIT), standing (STAND) and supported standing (S-STAND)

Absolute error (AE)	Test		Retest		Test–retest difference			
	Mean	SD	Mean	SD	Mean	SD	95% CI	<i>P</i>
SIT (<i>n</i> = 39)	1.31°	0.52°	1.31°	0.58°	0.00°	0.53°	−0.2:0.2	0.99
STAND (<i>n</i> = 39)	1.24°	0.54°	0.95°	0.41°	0.29°	0.58°	0.1:0.5	0.003
S-STAND (<i>n</i> = 11)	0.68°	0.36°	0.61°	0.18°	0.08°	0.33°	−0.1:0.3	0.44

Table 4 Measures of Absolute and Relative Reliability together with results from tests of heteroscedasticity of the tests in sitting (SIT), standing (STAND) and supported standing (S-STAND)

	Reliability			Heteroscedasticity	
	ME	ICC	95% CI Low	<i>r</i>	<i>P</i>
SIT (<i>n</i> = 39)	0.38°	0.54	0.27	0.27	0.11
STAND (<i>n</i> = 39)	—	—	—	—	—
S-STAND (<i>n</i> = 11)	0.23°	0.36	−0.28	0.61	0.07

Fig. 3 Test–retest plots of the absolute reposition errors (AE) in degrees during pelvic tilts in **a** sitting (SIT), **b** standing (STAND) and **c** supported standing (S-STAND)

Discussion

The aim of this study was to further test the reliability of inclinometry as a way of assessing dynamic control of the lumbopelvic complex. In contrast to earlier reports [9, 10], we were not able to show satisfactory reliability

of the method. In this study a test–retest design was chosen in order to evaluate the stability of the measurement between tests and a single measure reliability model was applied. This choice was made because application of the method should encompass only one test session (six targets and six estimates) per subject.

It has proven very difficult to do a complete sub-classification of LBP and diagnostic methods aiming at measuring dynamic control should have more than moderate reliability if the test is to be of any clinical and experimental value. Applying inclinometers is a simple procedure and could as such easily be applied in clinical settings. However, the insufficient reproducibility demonstrated in this study with healthy subjects under strictly standardised conditions, precludes its use in clinical and experimental settings that deal with the lumbopelvic complex.

Relative reliability examines the relation between two or more sets of repeated measures and is based on correlation coefficients: in particular the intraclass correlation coefficients (ICC). At least three slightly different models of ICC are suggested as measures of relative reliability of a single measurement [34]. The model chosen in this study, ICC(2,1), is designed to produce generalised results, as the evaluated method is considered representative of a larger 'population' of similar methods.

Correlation coefficients are greatly affected by the range of the scores since they evaluate the consistency of an individual's position within a group. If the group as a whole shows little variability in the measure of interest, there is little mathematical basis for determining relative positions and the correlation may be erroneously low [17]. On the other hand, if the group variability is large, there is a risk that correlation becomes unreasonably high. Accordingly, measures of absolute reliability must be included in the analysis. Measures of absolute reliability can be used to distinguish low retest reliability coefficients caused by variability within subjects from low coefficients caused by narrow ranges of values within the study sample [17]. Within-subject standard deviation is calculated from the square root of the error mean square term (EMS) obtained from a two-way analysis of variance. This term of absolute reliability is called measurement error (ME). This statistic is unaffected by the range of the measured values and represents a useful tool for evaluating absolute reliability.

In a former study of the method [9], similar reliability coefficients were found, however, it was also suggested that if the method was tested on a larger sample, the reliability could be improved. We increased the number of test subjects more than twice and failed to show improved reliability. In our study, the standing test procedure (STAND) could not confirm the previously reported ICC of 0.51 and we were compelled to abort the reliability calculation due to a highly significant systematic difference between test and retest. Only when the subjects were tested in sit-

ting position (SIT) or in supported standing (S-STAND), appropriate reliability assessments were possible, but without satisfactory results. The ICC(2,1) of 0.54 in the present study is similar to other methods that deal with assessment of dynamic control [27]. Most of the research performed in this area has been conducted on peripheral joints, in which specific diagnoses are more often available, and other methods of assessing dynamic sensory-motor control are accessible. In contrast, a valid comparator is not obvious in methods investigating the lumbopelvic complex, since they are originally designed for peripheral joints. The comparison of the test results is further inhibited by the use of different models of ICC, populations, and joints.

Standard error of the measurement (SEM) is an often-used statistic to measure the absolute reliability, which has been stated to be the most important form of reliability when changes in performance over time are to be detectable [17]. Brumagne et al. [9] followed the conventional reporting style and applied SEM as a measure of the absolute reliability. They claimed that SEM of 0.4° – 0.5° support the moderate relative reliability and the overall reproducibility of the method. Because SEM is dependent on the range of the data as well as the reliability coefficients, it is not an independent absolute measure and the results should be interpreted with caution. In the present study, measurement error (ME) was used and indicated good absolute reliability.

As a measure of relative reliability ICC(1,1) has been used in a former study [9]. However, this model of ICC is designed for the testing of inter-tester reliability and is only recommended if the sources of variability are limited. A limitation of the reliability in the studies of dynamic control, including the present, stems from the fact that the results from each test are based on an average of trials to reproduce target positions. Such a protocol gives a good mathematical basis for reducing the impact of variability between trials, and ought to increase reliability. In light of this fact, the demands on the reliability coefficient must rise, and further weakens the results. ICC values above 0.75–0.80 are recommended as the minimum for acceptable reliability [34]. With this in mind, the results from the present study show that the method has poor reliability.

Based on the former reliability report [9], studies have been performed using inclinometry [11, 12]. In one study [11], the procedure was applied in sitting position, a test position that at the time had not yet been assessed for reliability. As shown in the present study, the sitting procedure lacks reliability and for that reason the results of the mentioned study should be interpreted with caution.

The results of the present study demonstrate a significant difference between test and retest in the standing position (STAND), but not in the sitting position (SIT). The reason could be the choice of order of the test positions. The first test position was STAND followed by SIT. A learning effect may have influenced the results because the participants had opportunity to practice and get acquainted with the test movement in standing and transfer this to the sitting position. Their ability to perform the movement in test and retest may have been improved in the sitting position. Furthermore, in SIT, the amount of tactile input from the back of the thighs and gluteal regions can play a significant role in determining pelvic positions and blur the information about the dynamic control of the lumbopelvic complex. By consequence, a sitting position is not desirable if the intrinsic dynamics of sensory-motor control is at aim.

By omitting the first of the three repetitions, an attempt to minimise the effect of learning was made. Still, systematic and significant shift of the results was observed in STAND. One explanation could be learning, but the study was not designed to evaluate this. No significant difference between tests and retests was observed in SIT and S-STAND, indicating that the significance of learning was eliminated, but still the reliability was not acceptable.

In a pilot study, it was observed that postural sways in the standing position was increased due to the eliminated vision. The increased sway could have influenced the inclination of the sacrum and thus, the measurements of the target and estimated positions leading to unwanted variability and subsequent poor reliability. It is possible that the subjects actually reproduced the positions accurately, but that the measurement device was not able to record it due to postural sways. We attempted to control for the sway in the S-STAND by allowing the subjects to stand with elbow support in order to reduce the postural sway. However, the method still showed unacceptable reliability.

Our rather small AE values ranged between 0.64 and 1.1° could indicate excellent reproducibility. However, when the relatively limited test range of motion in a pelvic tilt is considered, there is a fair chance that target positions were reproduced by chance. Thus, a situation in which it is 'impossible' to miss the target position by more than 1 or 2° could be present, in which case even small variations become a threat to reliability and precision. In addition, the range of data can influence the ICC values negatively [17], which certainly could be the case in the present study. However, generally low lower limits of the 95%

CI of ICC, the systematic bias, possible overflow of tactile information in SIT together with a tendency towards heteroscedasticity in S-STAND indicate that the method is not reliable.

Perhaps dynamic sensory-motor control cannot be gauged in a complex anatomical and physiological region as the lumbopelvic with the present time technology avail. The lumbopelvic complex encompasses the lower part of the spine, the pelvis and both hip joints together with numerous muscles, ligaments and other soft tissues—all possible sources of variation when it comes to dynamic sensory-motor control. To draw reasonable conclusions based on a simple measurement is not possible at the present point. Future advances in technology and an increased knowledge of low back physiology are needed in order to clinically assess dynamic sensory-motor control in a reliable manner.

Conclusion

In conclusion, the inclinometry during pelvic tilt is not a reliable method for measuring dynamic control of the lumbopelvic complex. Pelvic tilts may or may not be true tests of dynamic lumbopelvic control, and dynamic lumbopelvic control may or may not have anything to do with clinical low back pain. However, if the tests are unreliable, they cannot be used as they have been in future research and prior work utilising these tests are now suspect. Until a satisfactory evaluation of the method is presented, further development of applicable methods to describe the dynamic sensory-motor control of the lower back region is needed. Extensive experimental research in the field of neuromuscular function of the low back is performed worldwide, but an appropriate clinical measure is yet to be presented.

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