Intraexaminer and Interexaminer Reliability of Pressure Biofeedback Unit for Assessing Lumbopelvic Stability During 6 Lower Limb Movement Tests

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Abstract

Objective: The purpose of this study was to assess examiners' intrarater and interrater reliability to use a pressure biofeedback unit (PBU) during 6 lower limb movement tests based on Movement System Impairment classification model for low back pain (LBP) in people with nonspecific LBP.

Methods: Thirty subjects (13 men and 17 women) with chronic nonspecific LPB were assessed during 6 lower limb movement tests based on Movement System Impairment classification using a PBU. Each test was performed twice by 2 assessors with a 48-hour interval between test sessions. Reliability indices of PBU measures (intraclass correlation coefficient [ICC]) were calculated.

Results: Intrarater reliability for hip and knee movement tests was good to excellent ($ICC^{3,3}$, 0-.60-0.95). Interrater reliability for hip and knee movement tests was fair to excellent ($ICC^{2,3}$, 0.40-0.86). Standard error of the measurement and smallest detectable change for the movement tests ranged from 1.4 to 11.3 mm Hg and from 3.9 to 31.3 mm Hg, respectively.

Conclusions: The results of this study indicate that trained examiners can reliably perform PBU measures for patients with chronic LBP. (J Manipulative Physiol Ther 2013;36:33-43)

Key Indexing Terms: *Low Back Pain; Outcome Assessment; Movement*

Different classification systems have been recommended for use in patients with low back pain (LBP) to guide treatment.[1-5] Several studies have suggested that classifying patients with LBP into subgroups may result in better clinical outcomes.[3,6,7] Classification using the Movement System Impairment (MSI) model involves interpreting data from a standardized examination to assign a patient to a LBP subgroup. The clinician identifies mechanically related impairments and the associated symptoms across a series of tests of movements and positions to decide on the patient's LBP classification. One of the differences between the MSI model and other classification systems is the assessment of the patient's ability to maintain a stable lumbopelvic region when performing lower and upper limbs movement tests.[8-10] Specifically, during each limb movement test, the examiner makes a judgment about the timing of the lumbopelvic region movement relative to movement of the limb and the magnitude of the lumbopelvic region movement. The effect of the limb movement test on LBP symptoms is also assessed. Tests that are symptom provoking are immediately followed by standardized modifications to determine the role of lumbopelvic movement on the patient's symptoms. Overall, the modification involves minimizing or restricting lumbar movement during the limb movement and encouraging movement in other joints to accomplish the test movement. An improvement in LBP

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symptoms indicates that the initially identified lumbopelvic movement is an important contributor to the person's LBP symptoms.[10,11]

There is some evidence that supports the proposal that findings from the standardized limb movement tests assist in discriminating specific LBP subgroups from healthy people.[10-13] Scholtes et al[12] reported that patients with LBP involved in sports that require trunk rotation may move their lumbopelvic region earlier and to a greater extent during lower limb movements than back-healthy people. Increased lumbopelvic movement could be related both to the increased demand on lumbar spine structures and to the onset of the symptoms.[13]

Previous research has determined the validity of the MSI model for LBP classification.[5] It has also been shown that this classification can be reliably applied by trained clinicians.[14-17] Different studies have investigated inter-rater reliability of classification of patients with LBP based on MSI classification system. Those studies found κ values of 0.75[14] and 0.61.[17] Luomajoki et al[18] assessed reliability of 10 active movement tests (most of them based on MSI model) in patients with and without LBP. They found κ values ranging from 0.24 to 0.71 and 0.51 to 0.96 for interrater and intrarater, respectively. The reliability of clinicians to make judgments during individual tests from the examination, however, appears to vary across the examination tests.[18-20] In a study by Van Dillen et al, reliability of clinicians to assess symptoms during tests from the MSI examination was higher ($\kappa > 0.75$) than reliability of clinician judgments of performance during tests of alignment and movement ($\kappa > 0.40$ for 72% of the items).[19] Making judgments of timing and magnitude of lumbopelvic movement with individual test items could be even more challenging for the inexperienced or untrained clinician.[19,21] In addition, because clinician judgments during limb movement tests are based only on visual and tactile information, the data are limited to a categorical scale, that is, an impairment is present or absent. Such data limit the ability of the clinician to document small changes in performance over time that may occur with interventions directed at improving lumbopelvic stability. Therefore, it would be useful if clinicians could reliably quantify lumbopelvic movement and monitor the effectiveness of rehabilitative interventions designed to improve lumbopelvic movement during the performance of limb movement tests.

Pressure biofeedback units (PBUs) have been used in clinical practice to provide biofeedback during specific muscle contraction retraining[22,23] and lumbopelvic stabilization exercises.[24-26] The PBU is a pressure transducer consisting of a 3-chamber air-filled pressure bag connected to a sphygmomanometer gauge by a catheter. Movements of body segments cause volume changes in the pressure bag, which is registered on the device.[27] The accuracy of the apparatus is described as ±3 mm Hg, and it has a measuring range from 0 to 200 mm Hg.[28] Given that the PBU can be used to detect lumbopelvic movement during lower limb movements and assist in retraining movement patterns,[22-26,29] it is plausible that this device can also be helpful in the assessment of lumbopelvic movement during lower limb movement tests.

The objective of this study is to assess intrarater and interrater reliability of 6 lower limb movement tests based on the MSI model for LBP using a PBU in subjects with nonspecific LBP.

Methods

Subjects

A convenience sample of 30 subjects (13 men and 17 women) with chronic, nonspecific LBP who were either undergoing or initiating physical therapy treatment at the Pontifícia Universidade Católica de Minas Gerais clinic participated in the study. To be included, subjects had to have LBP for at least 3 months, be between 18 and 65 years of age, and have no previous experience with the movement tests of interest. Subjects were excluded if they had neurologic signs, specific spinal pathology (eg, malignancy, inflammatory joint disease, bone disease), if they had undergone back surgery, or if they were not able to perform the movement tests for any reason. Subjects who reported osteoarthritis or disk lesions (without neurologic compromise) with or without leg pain were eligible to participate in the study. This project was approved by the ethics committee of the Pontifícia Universidade Católica de Minas Gerais, PUC-Minas, MG, Brazil, and all subjects signed the informed consent form.

Assessors

Both assessors were physical therapists. Assessor 1 had 1 year of experience in orthopedic physical therapy. Assessor 2 had 4 years of experience in orthopedic and manual physical therapy. Both assessors were trained by the first author, who had 12 years of experience in orthopedic physical therapy and had been using the MSI model in practice for 7 years. During the training period, the assessors had the opportunity to practice the movement tests several times with people with orthopedic conditions other than LBP who were receiving treatment at the Pontifica Universidade Catolica de Minas Gerais Clinic and with asymptomatic people.

Materials

A digital inclinometer (Dualer IQ; J Tech Medical Industries-Heber city, UT, USA) was used to measure knee and hip angles during the movement tests. The accuracy of the instrument is ±1°.[30]

Fig 1. *Hip flexion test. Hip movement was interrupted in 3 different hip flexion positions (30°, 60°, and 90°) so that the PBU pressure could be recorded by the assessor.*

A PBU (Stabilizer Pressure Biofeedback-Chattanooga Group, USA) was used to assess lumbopelvic movement during the lower limb movement tests. The same PBU unit was used throughout the study to avoid between-device differences.[31] To ensure accuracy of the PBU measurements, the device was pretested by loading the biofeedback unit cushion for 24 hours with 4 kg. The PBU unit was only considered adequate if the device lost no more than 0.5 mm Hg during the 24-hour period.[31] The same examination table was used throughout the study.

Lower Limb Movement Tests

Before beginning the movement tests, 4 anatomical references were marked with a pen while the subject was in standing. The landmarks were the anterior superior iliac spines (ASIS) and posterior superior iliac spines bilaterally. The marks were used to assist with positioning of the PBU.

All movement tests performed in this study were based on the MSI model for LBP described by Sahrmann.[4] In supine, subjects performed hip flexion to 3 joint positions (30°, 60°, and 90°) (Fig 1) and knee extension into 3 joint positions (30°, 60° and 90°) (Fig 2). In prone, subjects performed hip extension to 15° (Fig 3), hip internal and external rotation to 30° each (Fig 4), and knee flexion to 3 joint positions (30°, 60°, and 90°) (Fig 5). For all tests, the PBU was positioned against the lumbopelvic region so that PBU pressure reading could be recorded by the assessor. During subject's performance on the movement tests, each examiner recorded the PBU values (measured in millimeters of mercury) for each joint position described above.

During the tests, all subjects were wearing shorts (men) and a tank top (women). To familiarize subjects with the test, subjects performed the test movement 5 times. The lower limb (right or left) to be tested was determined randomly. For each test, 3 consecutive movements were performed, and the PBU values were recorded with each movement. The mean value of the 3 trials/movement was used for the analyses.

Procedures

Before measurements were taken on the first day, subjects were interviewed by assessor 1 to ensure that they fit the inclusion and exclusion criteria. Each subject completed the Brazilian-Portuguese version of Roland-Morris Disability Questionnaire.[32] Subjects currently receiving physical therapy treatment were required to perform the movement tests before their scheduled treatment session. Subjects recruited on their first physical therapy visit were required to start the physical therapy sessions after data collection.

Each set of 6 tests was performed twice within a 48-hour interval. On each test day, both assessors performed the set of movement tests in the same order: first assessor 1 and second assessor 2. Both assessors were blinded to the other assessor's test results. Data forms were collected by the first author after each testing session.

Fig 2. *Knee extension test. Knee extension movement was stopped in 3 different positions (30°, 60°, and 90°) so that the PBU pressure could be recorded by the assessor.*

Fig 3. *Hip extension test. Hip extension movement was stopped at 15° so that the PBU pressure could be recorded by the assessor.*

Description of Lower Limb Movement Tests

Hip Flexion Test. With the subject lying supine with the hips and knees extended, the PBU was positioned under the lumbar spine so that the inferior border of the device was aligned with the posterior superior iliac spine marks. The digital inclinometer was fixed with a strap on the lateral aspect of the distal part of the femur to be moved. The other thigh was fixed in an extended position with a strap over its distal part.

Fig 4. *Hip external/internal rotation test. Hip internal/external rotation movements (30°) were stopped so that the PBU pressure could be recorded by the assessor.*

Fig 5. *Knee flexion test. Knee flexion movement was stopped in 3 different positions (30°, 60°, and 90°) so that the PBU pressure could be recorded by the assessor.*

After the subject was positioned, the digital inclinometer was set to 0°, and the PBU was inflated to 40 mm Hg pressure.[28] The subject was then asked to flex the hip, moving his knee toward the chest, without touching the table with his foot. The movement was interrupted in three different hip flexion positions (30°, 60°, and 90°) so that the pressure registered in the PBU could be recorded by the assessor. If the subject could not reach 90° of flexion, the maximum hip flexion was used. In this case, this range of movement (ROM) was recorded and then used in all other measurements and by the other examiner (Fig 1).

Knee Extension Test. The subject and the PBU were positioned as described for the hip flexion test. The digital inclinometer was fixed with a strap just superior to the lateral malleolus. Two parallel vertical bars attached to both sides of the table and a horizontal bar fixed to the vertical bars were used in this test, allowing subjects to control hip position during knee movement. A similar experimental set-up has been used in studies to assess hamstring flexibility.[33]

The subject was instructed to flex his hip until the thigh contacted the horizontal bar (90° of hip flexion, controlled by a standard goniometer) and to fully flex his knee. At this point, the digital inclinometer was set to 0°, and the PBU was inflated to 40 mm Hg.[28] The subject then extended his knee while keeping his thigh in contact with the horizontal bar. The movement was interrupted in three different knee positions (30°, 60°, and 90° of extension from the starting point) so that the pressure shown on the PBU could be recorded by the assessor. If the subject could not reach 90° of extension, the maximum knee extension ROM was used. In this case, this ROM value was recorded and then used in all other measurements (Fig 2).

Hip Extension Test. The subject was in prone with the hips and knees extended. The PBU was folded and its central part (previously marked) was positioned against the ASIS on the same side of the lower limb being tested. The PBU was positioned against the ASIS to avoid contact with the abdominal muscles,[27,31] which would make it difficult to assess lumbopelvic movement.

The digital inclinometer was fixed with a strap on the lateral aspect of the distal part of the femur. The contralateral thigh was fixed in an extended position using a strap over the distal end of the femur. The digital inclinometer was set to 0°, and the PBU was inflated to 40 mm Hg. The subject was then instructed to raise his thigh, extending his hip to 15°, keeping the knee extended. At this point, the examiner recorded the pressure shown in the PBU (Fig 3).

Hip External/Internal Rotation Tests. With the subject and the PBU in the same position as described for the hip extension test, the subject flexed his knee to a 90° position. The digital inclinometer was fixed with a strap on the anterior aspect of the distal part of the tibia.

The digital inclinometer was set to 0°, and the PBU was inflated to 40 mm Hg.[28] The subject was instructed to rotate his leg in toward the midline (hip external rotation) and then out away from the midline (hip internal side) without moving his or her thigh laterally (abduction). The examiner recorded the pressure shown by the PBU at 30° of each hip rotation movement. If the subject was unable reach 30° of hip rotation, the maximum rotation was used. In this case, this maximum hip rotation was recorded and then used in all other measurements (Fig 4).

Knee Flexion Test. With the subject and PBU in the same position as described in the hip extension test, the digital inclinometer was fixed with a strap just superior to the lateral malleolus. The digital inclinometer was set to 0°, and the PBU was inflated to 40 mm Hg.[28] The subject was instructed to flex his knee, moving the ankle towards the buttock. The movement was interrupted in 3 different knee flexion positions (30°, 60°, and 90°) so the pressure registered in the PBU could be recorded by the assessor. If the subject was unable to reach 90° of flexion, the maximum knee flexion was used. In this case, this ROM value was recorded and then used in all other measurements (Fig 5).

Statistics

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS 12.0; SPSS, Chicago, IL). Mean values were calculated for the 3 movements for each test.

An intraclass correlation coefficient (ICC) was calculated to assess intrarater ($ICC^{3,3}$) and interrater ($ICC^{2,3}$) reliability of each movement test at each joint position. The ICC is a reliability coefficient ranging from 0.00 to 1.00. It is calculated using variance estimates obtained through an analysis of variance.[34] According to the Fleiss' classification,[35] ICC values above 0.75 indicate excellent reliability, values between 0.40 and 0.75 are fair to good, and values below 0.40 indicate poor reliability. Intrarater reliability was calculated for both assessors (1 and 2) for data collected on days 1 and 2. Interrater reliability was calculated using data from both assessors obtained on day 1. The standard error of the measurement (SEM) was calculated using the formula $SEM = SD \sqrt{1\text{-}ICC}$.[36] The smallest detectable change (SDC) was calculated using the formula $SDC = \sqrt{2} \times 1.96 \times SEM$.[37]

Results

A total of 30 subjects (17 women and 13 men) completed the study. Characteristics of study sample are presented in Table 1. Mean, SD, and minimum and maximum values for pressure-based unit measures during lower limb tests for both assessors on test days 1 and 2 are shown in Table 2. The ICC values for intrarater reliability with its respective SDC and SEM are presented in Table 3. The ICC values for interrater reliability with its respective SDC and SEM are presented in Table 4.

The test of hip flexion (90°) had excellent intrarater and interrater reliability (ICCs >0.75). The hip flexion tests at other angles (30° and 60°) had excellent intrarater reliability (ICC, 0.76-0.95) and fair to good interrater reliability (ICC,

Table 1. *Subject characteristics*

Characteristic	Value
Mean age in years (SD)	46.8 (11.1)
Mean height in centimeters (SD)	164 (0.1)
Mean weight in kilograms (SD)	71.6 (12.4)
Mean pain intensity-visual analog scale in centimeters [a] (SD)	6.4 (1.5)
Mean symptom duration in months (SD)	60 (43.5)
Location of current symptoms [b] (%)	
Low back only	23 (76.6)
Low back/proximal lower extremity (LE)	5 (16.7)
Low back/proximal LE/distal LE	2 (6.7)
Mean Roland-Morris Disability Questionnaire scores (0-24) (SD) [c]	12.6 (3.8)

LE, lower extremity.

[a] Roach KE, Brown MD, Dunigan KM, Kusek CL, Walas M. Test-retest reliability of patients reports of low back pain. J Orthop Sports Phys Ther 1997:26(5):253–9.[38]

[b] Definitions for location of symptoms from the Quebec task force on spinal disorders: low back, region from T12 to gluteal fold; proximal lower extremity, region from gluteal fold to knee; distal lower extremity, below knee. Spitzer WO, LeBlanc FE, Dupuis M. Scientific approach to the assessment and management of activity related spinal disorders: a monograph for clinicians. Report of the Quebec task force on spinal disorders. Spine 1987;12:S1e59.[39]

[c] Brazilian-Portuguese version of Roland Morris Disability Questionnaire.[32]

0.40-0.65). The tests of hip extension and internal rotation had good to excellent intrarater and interrater reliability (ICC, 0.60-0.87). The results also showed excellent intrarater reliability (ICC, 0.84-0.88) and good interrater reliability (ICC, 0.70) for the test of hip external rotation.

For the knee movement tests, the knee flexion test at 90° had excellent intrarater and interrater reliability (ICC, 0.77-0.89). The knee flexion test at 30° and 60° had good to excellent intrarater and interrater reliability (ICC, 0.68-0.86). All 3 knee extension tests (30°, 60°, and 90°) resulted in excellent intrarater reliability (ICC, 0.75-0.86) and fair to excellent interrater reliability (ICC, 0.49-0.77).

The SEM and SDC values for the movement tests ranged from 1.4 to 11.3 mm Hg and from 3.9 to 31.3 mm Hg, respectively. The lowest SEM and SDC values were observed for the hip external rotation test and the knee extension and flexion tests. The highest SEM and SDC values were obtained for the hip extension test.

Discussion

The present study demonstrated that a PBU showed satisfactory interexaminer and intraexaminer reliability to quantify lumbopelvic stability during lower limb movement tests. Our results showed that although ICC values varied according to the test being performed and joint angle, examiners attained clinically acceptable reliability with all tests. These findings are important because they demonstrate that PBU measures may be consistently applied as an outcome in studies of treatment directed at lumbopelvic stability.

The best reliability was obtained for measures of lumbopelvic stability with the hip flexion test at 90°. The ICC values ranged from 0.86 to 0.94. Roussel et al[40] also found excellent interrater reliability when assessing lumbopelvic stability using PBU during hip flexion movement (90°). However, during the test, subjects were instructed to maintain neutral spine position. In the current study, we chose to assess subject's natural movement without any stabilization instruction.

Our results also showed increasing PBU pressure values during hip flexion (30°, +1.6 mm Hg; 60°, +12.3 mm Hg; 90°, + 34.8 mm Hg). These PBU values and respective SEMs suggest that lumbopelvic movement, probably, posterior pelvic rotation (PPR) associated with lumbar flexion, occurred progressively across the hip flexion movement. Although several authors have reported that lumbar flexion and PPR movement usually contribute to total hip flexion angle in asymptomatic subjects,[41-44] lumbopelvic movement is expected to substitute for hip flexion/extension if there are any restrictions due to muscles or the hip joint capsule,[45] increasing the demand on lumbopelvic structures. Previous research has found that assessing lumbopelvic stability with PBU during hip flexion movement (knee lift abdominal test) may be useful for identification of dancers at risk for developing LBP.[40]

Good to excellent reliability was obtained for PBU values for the hip extension test. The ICC value for the hip extension test ranged from 0.69 to 0.85. Murphy et al[46] also reported good interrater reliability when assessing lumbopelvic stability during hip extension in prone position. However, the test outcome in this study was limited to presence or absence of lumbopelvic movement.

The mean increase in PBU values observed during hip extension was 19.1 mm Hg, suggesting some lumbopelvic movement. Previous research has described that abnormal lumbar spine movement during hip extension is also found in healthy young subjects.[47] Hip flexor stiffness/tightness and deficits in abdominal muscle control may contribute to this movement pattern.[4]

Hip rotation movements showed good to excellent reliability. Hip internal rotation movement increased PBU pressure by 16 mm Hg, whereas hip external rotation decreased PBU pressure by 10.9 mm Hg. The difference in the sign of the values is related to the direction of pelvic rotation during those movements, with hip internal rotation producing contralateral pelvic rotation and hip external rotation producing ipsilateral pelvic rotation. Excessive and earlier pelvic rotation during hip rotation in prone has been described in people with LBP.[12]

Knee movement tests showed some differences in reliability coefficients for different knee angles. Knee flexion at 90° provided excellent intrarater and interrater reliability, whereas other knee flexion angles showed good

Table 2. *Mean ± SD (minimum-maximum) for pressure-based unit measures in millimeters of mercury during lower limb tests for both assessors on test days 1 and 2 (n = 30)*

	Assessor 1		Assessor 2	
	First day	Second day	Fist day	Second day
Hip tests				
Flexion 30°	44.6 ± 6.0 (36.3-61.3)	44.3 ± 6.6 (32.6-60.0)	38.3 ± 3.9 (31.6-49.6)	39.4 ± 4.3 (30.6-50.6)
Flexion 60°	55.6 ± 8.2 (38.3-75.3)	55.8 ± 8.5 (37.3-81.3)	47.1 ± 7.8 (36.0-65.0)	50.5 ± 9.5 (35.0-81.3)
Flexion 90°	73.8 ± 16.8 (34.6-110.0)	76.4 ± 15.0 (49.3-114.6)	72.1 ± 19.1 (38.0-128.3)	76.8 ± 19.8 (50.3-134.6)
Extension	57.1 ± 22.2 (12.6-100.6)	57.1 ± 18.7 (20.0-89.3)	60.4 ± 22.1 (22.6 -120.0)	61.6 ± 17.4 (30.0 -116.6)
Rotation internal	58.2 ± 12.0 (24.0-85.3)	58.7 ± 10.0 (42.3-78.0)	52.5 ± 8.5 (36.3-72.6)	54.6 ± 9.1 (43.3-74.6)
External	26.8 ± 5.5 (12.0-34.0)	27.4 ± 4.7 (14.0-33.3)	30.6 ± 4.6 (14.6-36.0)	31.5 ± 3.8 (21.6-40.3)
Knee tests				
Flexion 30°	39.0 ± 4.4 (28.0-46.6)	38.1 ± 4.0 (30.0-46.0)	38.1 ± 3.4 (27.6-44.6)	39.6 ± 3.5 (34.0-50.6)
Flexion 60°	33.0 ± 4.5 (22.6-42.0)	32.4 ± 3.8 (20.6-38.3)	33.9 ± 3.7 (22.0-38.3)	35.3 ± 3.6 (26.6-42.6)
Flexion 90°	28.2 ± 7.1 (10.6-42.0)	27.9 ± 6.3 (8.6-38.6)	30.7 ± 5.4 (14.6-38.0)	31.9 ± 5.2 (14.3-39.6)
Extension 30°	40.5 ± 2.8 (36.0-49.3)	39.5 ± 3.6 (31.3-49.3)	38.5 ± 3.4 (24.3-44.0)	39.0 ± 3.6 (25.3-49.3)
Extension 60°	43.6 ± 4.2 (36.6-54.0)	42.6 ± 4.7 (31.3-54.0)	40.4 ± 4.0 (28.3-49.3)	41.2 ± 4.2 (34.0-52.6)
Extension 90°	54.5 ± 8.4 (40.0-74.6)	52.9 ± 8.1 (40.0-71.0)	50.3 ± 8.1 (37.3-68.6)	50.0 ± 8.4 (38.3-66.6)

Table 3. *Intraclass correlation coefficient values (95% confidence interval), SEM, and SDC values for intrarater reliability of pressure-based unit measures*

	Intrarater 1	SEM (mm Hg)	SDC (mm Hg)	Intrarater 2	SEM (mm Hg)	SDC (mm Hg)
Hip tests						
Flexion 30°	0.76 (0.50-0.89)	3.1	8.6	0.79 (0.56-0.90)	1.9	5.2
Flexion 60°	0.95 (0.88-0.97)	1.9	5.2	0.85 (0.69-0.93)	3.4	9.3
Flexion 90°	0.94 (0.87-0.97)	3.9	10.8	0.91 (0.80-0.96)	5.8	16.1
Extension	0.85 (0.69-0.93)	7.9	21.9	0.69 (0.34-0.85)	11.0	30.5
Internal rotation	0.60 (0.16-0.81)	7.0	19.3	0.87 (0.72-0.94)	3.2	8.8
External rotation	0.88 (0.74-0.94)	1.8	4.9	0.84 (0.65-0.92)	1.7	4.7
Knee tests						
Flexion 30°	0.83 (0.63-0.92)	1.7	4.8	0.68 (0.32-0.85)	1.6	4.4
Flexion 60°	0.69 (0.35-0.85)	2.3	6.3	0.76 (0.49-0.89)	1.8	5.0
Flexion 90°	0.86 (0.70-0.93)	2.5	7.0	0.89 (0.76-0.95)	1.8	4.9
Extension 30°	0.75 (0.47-0.88)	1.6	4.4	0.84 (0.67-0.93)	1.4	3.9
Extension 60°	0.77 (0.51-0.89)	2.1	5.9	0.84 (0.66-0.92)	1.6	4.5
Extension 90°	0.79 (0.57-0.90)	3.8	10.5	0.86 (0.72-0.94)	3.1	8.6

In all ICC tests, $P < .001$.

to excellent reliability. The differences in mean PBU values and respective SEM values during knee flexion indicate that lumbopelvic movement occurs at each knee flexion angle (30°, −1.3 mm Hg; 60°, −6.4 mm Hg; 90°, −10.4 mm Hg). Previous research has shown altered lumbopelvic stability during this movement in people with LBP.[12] For the knee extension tests, the ICC values showed excellent intrarater reliability and fair to excellent interrater reliability. The differences in PBU values during knee extension movement and respective SEM indicate that lumbopelvic movement occurred only in 90° knee extension position (30°, −2.5 mm Hg; 60°, +2 mm Hg; 90º, +11.9 mm Hg).

The SEM values found for the movement tests ranged from 1.4 to 11.3 mm Hg. These measurements represent the expected error when those tests are repeated. We did not find any other studies that reported SEM values for those tests using a PBU. However, we considered the SEM values found in this study acceptable. The mean SEM value found in hip flexion (90º) represented 6.9% of the mean range of PBU values found in this position. This was the lowest percentage value among all tests. On the other hand, the mean SEM value found in hip internal rotation represented 13.3% of the mean range of the PBU values at this position. This was the highest percentage value among all tests.

When considering the SDC analyses, the mean SDC value found for hip flexion (90º) represented 19.3% of the mean range of PBU values found in this test. This was the lowest percentage value among all tests. On the other hand, the mean SDC value found in hip internal rotation represented 37.1% of the mean range of the PBU values at this position. This was the highest percentage value among all tests. Smallest detectable change values should

Table 4. *Intraclass correlation coefficient values (95% confidence interval), SEM, and SDC values for interrater reliability of pressure-based unit measures*

	Interrater	SEM (mm Hg)	SDC (mm Hg)
Hip tests			
Flexion 30°	0.40 (−0.35-0.75)	3.8	10.6
Flexion 60°	0.65 (−0.29-0.89)	4.7	13.1
Flexion 90°	0.86 (0.71-0.94)	6.7	18.6
Extension	0.74 (0.45-0.87)	11.3	31.3
Internal rotation	0.61 (0.14-0.82)	6.4	17.7
External rotation	0.70 (−0.08-0.89)	2.8	7.7
Knee tests			
Flexion 30°	0.86 (0.69-0.93)	1.5	4.0
Flexion 60°	0.80 (0.58-0.90)	1.8	5.0
Flexion 90°	0.77 (0.46-0.89)	3.0	8.3
Extension 30°	0.49 (−0.08-0.76)	2,2	6.1
Extension 60°	0.63 (−0.12-0.86)	2.5	6.9
Extension 90°	0.77 (0.36-0.91)	4.0	11.0

In all ICC tests, $P < .001$.

be considered when clinicians are looking for changes in lumbopelvic stability by using PBU measurement during treatment. Lower SDC values are recommended so that a measure can be sensitive to change.[48] Tests with higher SDC values, especially when associated with lower range of PBU values, are more limited as a clinical tool. When considering those observations, we can conclude that (1) hip flexion test at 90º is preferred against other hip flexion angles; (2) knee flexion test at 90º is also preferred against other knee flexion angles; (3) hip external rotation test is preferred against hip internal rotation test; and (4) hip internal rotation, hip extension, kip flexion at 30º, knee flexion at 60º, and knee extension at 90º tests are less sensitive to changes because their SDC values represented more than 30% of the range of its PBU values.

Study Limitations

Using a PBU to assess lumbopelvic stability has some limitations. Although changes in PBU values are associated with lumbopelvic movement,[28,29] the measures primarily derive from changes in pressure that body segments exert upon the transducer. This means that the same amount of lumbopelvic movement in subjects with different body weights could result in different magnitudes of changes in PBU measurements, especially when testing procedures involve significant dislocation of the center of mass—such as the hip flexion test. The fact that changes in PBU measurements might be influenced by body weight and dislocation of the center of mass limits the comparisons that can be drawn between the performances of different subjects. However, PBU measurements can still be used to follow the patients during treatment. After selecting tests and joint angles that provide good reliability, acceptable SEM and SDC values, therapists can reassess the tests and check if lumbopelvic stability has improved for that subject because influence of weight and dislocation of center of mass on PBU values should not change with time.

If the purpose of the PBU measurement is to compare different subjects, normalization procedures should be developed beforehand. We are unaware of any study that provided such normalization procedure. Data normalization is used to reduce the effects of a covariate on different dependent variables such as force and electromyography.[49,50] Examining the range of PBU values from maximum anterior pelvic rotation (APR) to maximum PPR may be an alternative procedure to normalize values. This range could be considered total lumbopelvic movement that can occur by the influence of lower limb movements. Thus, the results of lower limb tests from different subjects could be compared by calculating what percentage of total lumbopelvic movement occurred (PBU change observed during test × 100/PBU range from maximum pelvic movements). Investigation of normalization procedures for PBU measures should be considered in future studies.

During the tests performed in prone position, a baseline PBU pressure of 40 mm Hg was used. Although previous studies have suggested this value for supine position tests,[25,26,29,40] the baseline value for prone position tests was not yet defined when assessing lumbopelvic movement. Other studies have considered a baseline PBU pressure of 70 mm Hg in prone position.[22,23] However, in those studies, PBU was used to assess muscle contraction, not lumbopelvic movement, and it was positioned against the abdominal wall, not against the pelvis. In this study, we chose to keep the same baseline pressure that is used for the supine position.

Another limitation is that the PBU is limited in its ability to differentiate between different directions of pelvic rotation movements. During the tests, an increase in PBU value (>40 mm Hg) could be related to PPR/lumbar flexion in tests performed in supine and to APR/lumbar extension in tests performed in prone. A decrease in PBU value (<40 mm Hg) could be related to APR/lumbar extension in supine tests and to PPR/lumbar flexion in prone tests. Because the PBU was positioned in one side of the pelvis (AISIS) in the tests in prone, it is possible that, for example, an increase in PBU value would not be related to APR but to pelvic rotation to the opposite side. Repeating the test with the PBU positioned in the contralateral ASIS may probably solve this issue. For APR movement, both PBU positions (right and left AISIS) must produce an increase in pressure. For pelvic rotation movement, the values should increase in just one PBU position (right or left AISIS) or more in one PBU position than the other in case of combining APR + pelvic rotation. The primary objective of this study was to assess the repeatability of those tests results using PBU. Future studies should investigate validation of PBU to detect different lumbopelvic movements or combination of them.

Conclusions

The results of this study showed that the PBU provided consistent measures of lumbopelvic stability during lower limb movement tests. When assessing lumbopelvic stability with hip flexion or knee extension or flexion, the 90° position has the best reliability compared with other joint positions. The hip external rotation movement test had better reliability for assessing lumbopelvic stability when compared with the hip internal rotation movement test.

Practical Applications

- Pressure biofeedback unit measures are affected not only by lumbopelvic movement but also by body weight and center of mass change.
- When assessing lumbopelvic stability with hip flexion or knee extension or flexion, the 90° position has the best examiner reliability compared with other joint positions.

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