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ORIGINAL ARTICLE

Postural balance in low back pain patients: criterion-related validity of centre of pressure assessed on a portable force platform

Thomas Maribo · Berit Schiøttz-Christensen · Lone Donbæk Jensen · Niels Trolle Andersen · Kristian Stengaard-Pedersen

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Abstract
Introduction Altered postural control has been observed in low back pain (LBP) patients. They seem to be more dependent on vision when standing. The objective of the study was to determine concurrent and predictive validity of measures of postural stability in LBP patients.
Materials and methods Centre of Pressure (CoP) measurements were tested against pain, fear of pain, and physical function. Velocity, anterior–posterior displacement, and the Romberg Ratio obtained on a portable force platform were used as measures of postural stability.
Results Baseline and 12-week follow-up results of 97 LBP patients were evaluated. The correlations between CoP measurements and pain, fear of pain, and physical function were poor. There were no significant differences in CoP measurements between patients with no change or deterioration and patients with improvement in pain and back-specific function.
Conclusion This first study of concurrent and predictive validity of postural balance in LBP patients revealed no association between CoP measures and pain, fear of pain, and physical function.

Keywords Postural balance · Force platform · Validity · Low back pain · Centre of pressure

T. Maribo (✉)
Department of Physiotherapy and Occupational Therapy, Aarhus University Hospital, 8000 Arhus C, Denmark
e-mail: Thomas.maribo@aarhus.rm.dk

T. Maribo · K. Stengaard-Pedersen
Department of Rheumatology, Aarhus University Hospital, Arhus C, Denmark

B. Schiøttz-Christensen
Aarhus Rheumatology Clinic, Arhus C, Denmark

L. D. Jensen
Danish Ramazzini Center, Department of Occupational Medicine, Aarhus University Hospital, Arhus C, Denmark

N. T. Andersen
Department of Biostatistics, Institute of Public Health, Aarhus University, Arhus C, Denmark

Introduction

Postural balance involves dynamic interactions of vestibular, visual, and somatosensory information analyzed in a complex regulatory feedback system, resulting in constantly changing outputs [1, 2]. Well-functioning postural balance is necessary to maintain normal daily life [2, 3]. Postural stability is a subset of postural balance defined by the ability to maintain a specific posture [3] and often described by changes in centre of pressure (CoP) [4]. Many factors may contribute to decreases in postural stability, including ageing, neurological, or musculoskeletal disorders, e.g. low back pain (LBP) [5].

LBP is a common and costly musculoskeletal complaint. The term "persistent low back pain" is often used to describe subacute, chronic, and recurrent pain. Several studies indicate that LBP patients have poorer postural stability than healthy controls [6, 7]. It is not known whether poorer postural stability is a consequence or a predictor of LBP, but some evidence suggests that people with poor postural stability have an increased risk of LBP [8]. A decrease in somatosensory information has been suggested as a possible mechanism affecting postural balance, as LBP does not involve vestibular and visual senses [9].

The influence of LBP on postural balance is complex [10] and affected by co-existing factors: pain, fear of pain, positive

neurologic findings, adoption of an alternate movement strategy, and low muscular conditioning [4, 7, 9–11].

Postural stability has been assessed using various techniques; the force platform technique addressing CoP excursions is among the tools frequently used [6, 9, 12].

In laboratory settings, platforms are usually secured to the ground and their usage is costly, complicated, and time-consuming; such tests have not yet become part of daily routine [13]. As portable force platforms are becoming cheaper and their usage time-efficient, such devices appear relevant to daily practice.

A number of authors have reported that LBP patients are more dependent on vision compared to a healthy population [2, 4–6, 13]. Balance decreases in both LBP patients and healthy controls in eyes closed (EC) tests compared to eyes open (EO), but in EC tests the difference between LBP patients and healthy controls becomes more distinct [4]. No relevant outcome measures are presented to reflect this dependency. The intra-subject Romberg ratio (RR) quantifies the visual contribution to balance [14]. The RR is the ratio of a given value of EO and EC readings, respectively. The ratio could be a relevant outcome measure in rehabilitation as there is great inter-subject variability in CoP measures [8]. The RR seems to reflect this dependency on vision.

Well-documented reproducibility and validity is prerequisite for outcome measures to be useful to clinicians [15]. In a previous study, we found acceptable reproducibility of EC mean velocity (mVel) of CoP excursion and close to acceptable reproducibility of the RR of the mVel (RRvel) [16], but the validity has not been described.

The objective of this study was to determine the criterion-related validity of CoP excursion as a measure of postural stability in patients with LBP as assessed on a portable force platform. Concurrent validity was tested to outcome measures recommended in LBP evaluation: pain, fear of pain, and physical function. Predictive validity was compared to pain and back-specific function. We hypothesised a strong correlation between changes in CoP measures and changes in pain, fear of pain, and physical function. Furthermore, we hypothesised good predictive validity of CoP measures.

Methods

Subjects

The population in this validity study comprised 96 LBP patients referred from general practitioners to the rheumatologic outpatient clinics at Aarhus University Hospital or Aarhus Rheumatology Clinic for expert evaluation. Inclusion criteria were: persistent LBP, active on the labour market, age 18–63, and Danish-speaking. Exclusion criteria were: planned low back surgery, pregnancy, and serious other illnesses, e.g. vestibular diseases.

Experimental procedures

Test conditions (light, room temperature) were standardised before the tests, and all trials were conducted by one of two experienced physiotherapists.

CoP excursion was tested using a four-channel portable force platform (HurLabs BT4) that was calibrated prior to testing; channels were checked before every test. Patients were instructed to look straight ahead and stand as still as possible with arms hanging down. The foot position was standardised: a 2 cm heel-to-heel distance and an angle of 30° between the feet. The test was carried out with EO, focusing on a point 2 m ahead, and with EC. The participants stood still for at least 5 s (pre-phase) before the measurement. After the pre-phase, CoP was measured for the next 60 s; signals were sampled at 200 Hz and filtered with a digitally low-pass filter at 7.8 Hz cut-off frequency prior to sampling, signals were filtered with two low-pass filters, first stage filter is $sinc^3$ type and second stage filter is 22-tap filter. After a 10-min break, the procedure was repeated. Mean of two tests was used.

From COP data, the EC mVel, the mean anterior–posterior displacement (APdispl), and the mVel RR (RRvel) were considered for discussion.

The mVel is recommended as outcome parameter for postural stability [7, 12], the APdispl is used in a recent study [4], and the RRvel is used in order to quantify the visual contribution to posture. The RRvel is usually greater than one, and an RRvel of 1.3 indicates that mVel is increased by 30% in EC tests compared to EO.

When using this test protocol the reliability of mVel and APdispl seems reliable [12, 16]. A previous study showed just 1% from acceptable reliability in RRvel [16] using only one test session. To enhance reliability a mean of two tests was used [17].

Pain was assessed as mean pain during the last week rated on an 11-point numerical rating scale [18] and as SF-36 bodily pain. Fear of pain was identified using the physical activity part of the Fear Avoidance Beliefs Questionnaire. To measure alternate movement strategy we assessed function by means of the Roland Morris Questionnaire [19] and SF-36 physical function. Muscular condition was addressed via back muscle endurance using the modified Sorensen test [20], and maximal oxygen uptake (ml O_2/min/kg) using the Åstrand bicycle test [21].

Data collection

At inclusion and follow-up, a questionnaire was posted to the patients along with an appointment for testing. Any patients who failed to show up for testing were rescheduled

once. The physiotherapists were blinded to results from the questionnaire and to CoP results.

In order to reduce the risk of fatigue affecting CoP, patients had a 15-min rest prior to testing. Tests were completed in the following order: CoP, back muscle endurance, and maximal oxygen uptake.

The data collection was part of a randomised controlled trial [22]. As this study is a validity study the randomisation was of no interest, and all participants were included. The portable force platform was available from June 2008; participants in this study were enrolled from that point onwards.

Statistical analysis

Descriptive statistics were used to characterise participants. CoP data were logarithm-transformed to obtain an approximately normal distribution [23]. The Back-transformed mean equals the geometric mean and the standard deviation of the logarithm-transformed is an estimate of coefficient of variation (CV). Considering the influence of age and individual characteristics on CoP measures [12], analyses were conducted for both (1) non-normalised CoP measures and (2) CoP measures normalised relative to the subjects' age, height and weight as originally described by O'Malley and recommended for CoP analysis [12]. This procedure involves subtracting the estimated regression model figures from the original values of the CoP parameter and adding the mean value of the original data. This offers the advantage of keeping data in the same range and of retaining the original units. Intra-person change is calculated on basis of original data as changes are normally distributed.

Criterion-related validity was evaluated by means of concurrent and predictive validity analyses [15].

Concurrent validity was examined by correlating CoP with pain, fear of pain, and physical function measured at the same point of time [15] and through the correlation between changes in CoP and changes in pain, fear of pain, and physical function. Spearman's correlation coefficient (r) was used. Criterion validity was evaluated by the criteria described by Innes, which defined $r < 0.50$ as poor, $r \geq 0.50$ as moderate, and $r \geq 0.75$ as good criterion validity [15].

Predictive validity was tested using postural stability at inclusion and by examining whether measures were different in patients with a clinical relevant improvement compared to patients with no or negative changes [15]. The two most fundamental clinical outcomes (pain and back-specific function) were used [24]. Clinically relevant improvement was defined as a change of 30% or more [24]. A two-tailed p value of < 0.05 was considered statistically significant.

Results

Between June 2008 and April 2009, a total of 139 patients were tested for the study. Three patients were excluded after the test as results suggested vestibular balance disorders. We had a loss to follow-up of 39 patients (28.1%). There were no statistically significant differences in age, sex, LBP classification, or back-specific function between patients analysed and patients lost to follow-up.

Data from 96 LBP patients were analysed; the median follow-up time was 14.5 weeks (IQR 13.4–16.6 weeks). All patients had LBP for more than 8 weeks, ranging from 9 weeks to 30 years. Diagnostic and demographic data are presented in Table 1.

The mean intra-patient change from baseline to follow-up showed improvements in postural stability and all outcome measures as seen in Table 2. There were no statistically significant change in mVel, APdispl, or RRvel in the non-normalised data ($p = 0.43$, $p = 0.63$, and $p = 0.22$, respectively) or the normalised data ($p = 0.48$, $p = 0.75$, and $p = 0.22$, respectively). Changes in other outcome measures were statistically significant ($p < 0.05$).

Concurrent validity is presented in Table 3. Most of the correlation coefficients between mVel, APdispl, or RRvel and LBP relevant outcome measures were non-significant, and none of the associations showed concurrent validity higher than poor.

Predictive validity is presented in Table 4. 37 patients showed no change or deterioration, while 42 patients showed clinically relevant improvement (>30%) in pain; the same groups comprised 35 and 36 patients, respectively, when using back-specific function as outcome measure. We found no predictive validity in mVel or RRvel as there were no significant differences between the groups ($p > 0.05$).

Positive neurologic findings were found in 31% of our patients, and it seems safe to assume that postural stability is different in this particular sub-group. A sub-group analysis showed a significant difference in mVel ($p = 0.003$) in patients with positive neurologic findings. Further analysis on the sub-groups showed no change in validity results.

Discussion

In this first study of concurrent and predictive validity of postural balance in LBP patients, we found no association between CoP measures and pain, fear of pain, and physical function. Correlations were not clinically relevant, and most were even non-significant. Furthermore, we found no differences in CoP measures at baseline when comparing patients with clinically relevant improvements and patients with no change in back-specific function and pain.

Table 1 Patient characteristics and outcome measures at baseline

Variable		*n*
Age, mean (SD)	44.9 (10.0)	96
Female gender, *n* (%)	51 (53.1)	96
Body mass index (BMI), mean (SD)	30.1 (6.2)	96
Quebec Task Force classification		96
1 Without radiating pain, *n* (%)	29 (30.2)	
2 With radiating pain but not below knee level, *n* (%)	15 (15.6)	
3 With radiating pain below knee level, *n* (%)	52 (54.2)	
4 Positive neurologic findings, *n* (%)[b]	30 (31.2)	
Postural stability (normalised data)		
mVel EC, mm/s, mean (CV)[a]	15.6 (26%)	96
APdispl, mm, mean (CV)[a]	55.6 (29%)	96
RRvel (Romberg Ratio mVel), mean (SD)	1.40 (0.20)	96
Pain		
Mean pain during the last week (0–10), mean (SD)	5.9 (2.5)	92
SF-36 bodily pain (0–100), mean (SD)	46.5 (19.1)	95
Fear of pain		
Fear Avoidance Believes Questionnaire-physical activity (0–24), mean (SD)	10.9 (5.3)	91
Back-specific function		
Roland Morris Questionnaire (0–23), mean (SD)	10.5 (5.3)	94
SF-36 physical functioning (0–100), mean (SD)	72.2 (19.7)	96
Muscular conditioning		
Maximal oxygen uptake (ml O_2/min/kg), mean (SD)	31.3 (10.3)	92
Sørensen test, (0–240 s), median (IQR)	106 (49,169)	96

[a] Back-transformed mean;
[b] At least two abnormal results: unilateral abnormality in muscle strength, reflex, or sensation

Table 2 Postural stability and LBP-relevant outcome measures

Outcome	Mean intra-patient change	*n*
Postural stability		
mVel EC, mm/s	0.19 (2.73)	96
APdispl, mm	0.10 (10.02)	96
RRvel (Romberg Ratio mVel)	0.02 (0.19)	96
Pain		
Mean pain during the last week	1.77 (2.79)	90
SF-36 bodily pain	−10.48 (20.52)	94
Fear of pain		
Fear Avoidance Believes Questionnaire-physical activity	1.57 (6.75)	89
Back specific function		
Roland Morris Questionnaire	2.17 (4.58)	93
SF-36 physical functioning	−6.00 (15.63)	93
Muscular conditioning		
Maximal oxygen uptake (ml O_2/min/kg)	−2.64 (6.41)	84
Sørensen test	−20.71 (55.34)	93

Intra-person change between baseline and follow-up. Results are mean and SD

The results went counter to our hypothesis of good validity, prompting us to conclude that validity is low, non-existent, or that our results might be biased due to either population characteristics or measurement error.

Validity may also have been affected by the time scale; the time frame may have been too short to allow changes in balance to manifest themselves.

It is possible that impaired balance is present in just a subgroup rather than in all LBP patients, meaning that some patients should not be expected to experience any change in balance. As no reference values exist, we have no firm knowledge on this point.

Just three other studies reports concurrent and predictive validity of postural balance in LBP patients, Kuukkanenen

Table 3 Concurrent validity of postural stability

	Pain				Fear of pain		Function				Muscular conditioning			
	Mean pain during the last week		SF-36 bodily pain		FABQ-pa		Roland Morris Questionnaire		SF-36 physical functioning		Maximal oxygen uptake		Back muscle endurance	
At inclusion														
n	92		95		91		94		96		92		96	
mVel EC, mm/s	0.15	$p = 0.15$	−0.24	$p = 0.02$	0.09	$p = 0.40$	0.25	$p = 0.01$	−0.25	$p = 0.01$	−0.43	$p < 0.01$	−0.25	$p = 0.02$
APdispl, mm	0.03	$p = 0.76$	−0.09	$p = 0.39$	−0.11	$p = 0.31$	−0.07	$p = 0.53$	−0.17	$p = 0.09$	0.01	$p = 0.94$	−0.10	$p = 0.34$
RRvel	0.09	$p = 0.41$	−0.17	$p = 0.11$	−0.07	$p = 0.50$	0.04	$p = 0.71$	−0.06	$p = 0.57$	−0.13	$p = 0.23$	−0.16	$p = 0.13$
Normalised mVel EC	0.23	$p = 0.02$	−0.30	$p < 0.01$	0.02	$p = 0.82$	0.24	$p = 0.02$	−0.33	$p < 0.01$	−0.13	$p = 0.23$	−0.18	$p = 0.08$
Normalised APdispl	0.02	$p = 0.82$	−0.03	$p = 0.81$	−0.02	$p = 0.89$	−0.07	$p = 0.50$	−0.07	$p = 0.52$	−0.03	$p = 0.75$	−0.07	$p = 0.47$
Normalised RRvel	0.08	$p = 0.48$	−0.17	$p = 0.10$	−0.14	$p = 0.20$	0.01	$p = 0.89$	−0.09	$p = 0.36$	−0.05	$p = 0.62$	−0.11	$p = 0.29$
Change from inclusion to follow−up														
n	90		94		89		93		93		84		93	
mVel EC, mm/sec	0.18	$p = 0.08$	−0.15	$p = 0.16$	−0.05	$p = 0.65$	0.03	$p = 0.80$	−0.16	$p = 0.14$	−0.02	$p = 0.85$	−0.01	$p = 0.91$
APdispl, mm	0.05	$p = 0.66$	−0.02	$p = 0.83$	−0.19	$p = 0.07$	0.04	$p = 0.70$	−0.15	$p = 0.16$	−0.19	$p = 0.09$	−0.11	$p = 0.32$
RRvel	0.03	$p = 0.81$	−0.06	$p = 0.55$	−0.04	$p = 0.74$	−0.09	$p = 0.39$	0.13	$p = 0.20$	0.07	$p = 0.54$	0.04	$p = 0.72$
Normalised mVel EC	0.20	$p = 0.06$	−0.16	$p = 0.12$	−0.07	$p = 0.51$	0.02	$p = 0.83$	−0.15	$p = 0.15$	−0.04	$p = 0.70$	−0.01	$p = 0.95$
Normalised APdispl	−0.03	$p = 0.81$	−0.03	$p = 0.81$	−0.21	$p = 0.04$	0.04	$p = 0.71$	−0.15	$p = 0.14$	0.19	$p = 0.09$	0.09	$p = 0.38$
Normalised RRvel	0.06	$p = 0.57$	−0.07	$p = 0.49$	−0.05	$p = 0.64$	−0.04	$p = 0.70$	0.12	$p = 0.24$	−0.05	$p = 0.66$	0.03	$p = 0.77$

Correlation (r) to LBP-relevant measures and physical tests, non-normalised and normalised data

FABQ-pa Fear Avoidance Believes Questionnaire-physical activity

Table 4 Predictive validity of postural stability

	Pain						Roland Morris Questionnaire					
	Non-normalised data			Normalised data			Non-normalised data			Normalised data		
	No or negative change	Clinical relevant change	*p*	No or negative change	Clinical relevant change	*p*	No or negative change	Clinical relevant change	*p*	No or negative change	Clinical relevant change	*p*
n	37	42		37	42		35	36		35	36	
mVel EC, mm/sec at first visit, mean (CV)	16.2 (39%)	15.1 (30%)	0.36	15.7 (28%)	15.5 (24%)	0.88	15.0 (32%)	15.2 (37%)	0.88	15.4 (24%)	15.5 (27%)	0.84
APdispl EC, mm at first visit, mean (CV)	51.6 (41%)	54.6 (28%)	0.47	52.8 (35%)	55.1 (25%)	0.56	58.6 (30%)	54.1 (34%)	0.29	58.0 (23%)	53.6 (32%)	0.24
RRvel at first visit, mean (SD)	1.41 (0.25)	1.32 (0.19)	0.08	1.40 (0.21)	1.32 (0.20)	0.11	1.41 (0.19)	1.32 (0.21)	0.09	1.41 (0.19)	1.32 (0.21)	0.07

Patients are grouped in two according to pain and back-specific function: patients with minimal important change compared to patients with no or negative change during follow-up period. Difference in postural stability in the two groups are presented. Changes are presented as back transformed

and Mälkiä tested 82 LBP patients and found no association between CoP parameters and pain or functional capacity, which matches our results on concurrent validity [25]. No predictive value of the CoP parameters was found in their study either [25]. Takala and Viikari-Juntura found an association between mean displacement and future LBP in their study, but this was only seen in women [8]. In another study Takala et al. [26] found only slight associations between LBP and postural balance, but the results from the study are not clear. A recent review states: "There is insufficient data to suggest a relationship between pain intensity, previous pain duration or the level of perceived disability and the magnitude of COP excursions" [7]. The present study form part of evidence that contradicts such a relationship.

The importance of vision seems well documented theoretically [4, 5], but the present study was unable to show the same result. We found no other outcome measure representing dependency on vision in individuals. Most other studies reporting LBP patients to be more dependent on vision are comparing groups of LBP patients to healthy persons [2, 4–7, 13]. Further research is necessary to address the role of vision or, even better, the role of the somatosensory system on a single patient level.

We gave much consideration to the test procedure, e.g. static or dynamic testing, number of repetitions, visual condition, foot position, position of the arms, sampling frequency, and CoP parameters. In 2010, recommendations for CoP measures were published in order to reduce measurement errors [7, 12]. Although this study was planned before those recommendations became known, our study was in keeping with most of the recommendations. As we used old recommendations, a 60 s sampling duration was used instead of 90 s [7, 12]. This might have increased variability although the evidence behind the 90 s recommendations seems weak. A mean of 3–5 trials is recommended [7]; in this study, a mean of two trials was used. When considering one's choice of outcome measure, it will often be necessary to weigh up precision against clinical relevance. Five trials could be relevant in research, but as we wanted to test clinical feasibility, it would defy our particular purpose. One trial would be ideal from a clinical perspective. Just one trial is not reliable enough, however, as an earlier study showed a measurement error of 10.9% in mVel and 13.3% in RRvel using one test trial. In this study, we used two test trials, as this is shown to improve reproducibility [17].

The portable force platform was used to enhance clinical relevance as such platforms can fit into a normal examination room. If CoP measures were to be employed in standard examinations, it would seem necessary for platforms to be portable. We have found no studies comparing different test devices. Such studies seem relevant before putting portable platforms to use in the clinic.

Patients were referred from general practitioners to a rheumatologist for diagnostic evaluation of LBP. Almost all patients could be included and only a few patients refused to participate, making the external validity high.

In the calculations, we used mean pain during the last week. Some authors suggest an association between present pain and increased sway [11]. We measured actual pain when standing on the force platform: the results did not change when using present instead of mean pain during the last week, as correlations remained non-significant.

Conclusion

This first study of concurrent and predictive validity of postural balance in LBP patients found no association between CoP measures and pain, fear of pain, and physical function. Correlations were not clinically relevant, with most even being non-significant. No difference in CoP measures at baseline was found when comparing patients with clinically relevant improvement and patients with no change in back-specific function and pain.

There is a lack of reference values for different age groups in both healthy persons and LBP patients. Further research is necessary to address this issues.

The clinical use of CoP measures is limited by the unknown cause of the decrease in postural stability. Studies on the role of dependency on vision and the somatosensory system in LBP patients and studies in patients with positive neurologic findings could prove fruitful.

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Conflict of interest None of the authors has any potential conflict of interest.

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