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Original Article

Proprioceptive change impairs balance control in older patients with low back pain

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Abstract. [Purpose] This study aims to determine the specific proprioceptive control strategy used during postural balance in older patients with low back pain (LBP) and non-LBP (NLBP) and to assess whether this strategy is related to proprioceptive decline and LBP. [Subjects and Methods] Pressure displacement center was determined in 47 older persons with LBP and 64 older persons with NLBP during upright stance on a balance board without vision. Gastrocnemius (GS) and lumbar multifidus muscle (LM) vibratory stimulations of 60 and 240-Hz, respectively, were applied to evaluate the relative contributions of different proprioceptive signals (relative proprioceptive weighting ratio, RPW) used in postural control. Age, height, weight, back muscle strength, L1/2 and L4/5 lumbar multifidus cross section area ratio, skeletal muscle mass index, sagittal vertical axis, and Roland-Morris disability questionnaire (RDQ) were evaluated. [Results] Compared with older patients with NLBP, those with LBP showed a lower RPW 240-Hz, lower L4/5 lumbar multifidus cross-sectional area ratio, and a significantly higher age and RDQ. Logistic regression analysis showed that RPW 240-Hz and age were independently associated with LBP, after controlling for confounding factors. [Conclusion] Older patients with LBP decreased their reliance on GS (RPW 240-Hz) proprioceptive signals during balance control.

Key words: Relative proprioceptive weighting ratio, Balance control, Low back pain

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INTRODUCTION

An important factor in maintaining postural control is the gating of sensory sensation in accordance with the current posture to avoid undesirable responses triggered by external or internal perturbations[1)].

Muscle vibration, known to be a strong stimulus for muscle spindles and Vater-Pacini corpuscles, has been used to assess the role of proprioception[2, 3)]. However, the role of each proprioception (muscles spindles and Vater-Pacini corpuscles) in low back pain (LBP) was not evaluated in these studies[4, 5)]. Investigating the specific role of proprioception during individual stimulation conditions is essential to gain insight into the selection, variability of postural control strategies in LBP, and the possible role of impaired proprioception and trunk function decline.

This study aims to investigate the relationship between LBP risk and the proprioception of standing balance control in LBP and non-LBP (NLBP) older patients. The hypothesis was that decreased proprioception would be found in response

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to specific vibratory stimuli in patients with LBP and that these decreases would be associated with a risk of LBP in this population.

SUBJECTS AND METHODS

This study was carried out over a period of 3 year and 4 months (Nov 2012 to Mar 2016) during general clinical practice. Written informed consent was obtained from all participants before their inclusion in the study. All investigations were conducted according to the principles expressed in the Declaration of Helsinki. The Ethics Committee of the National Center for Geriatrics and Gerontology approved the study (Approval number: 26-7). A total of 111 older (age >65 years) persons were recruited for the study, including 47 individuals (22 women, 25 men) with LBP lasting over 3 months who visited the National Center for Geriatric and Gerontology for orthopedic treatment and 64 individuals with (24 women, 40 men) and NLBP as control subjects.

Control subjects were inpatients with no history of disabling LBP. The study subjects were patients with spinal column stenosis and spondylitis deformans who presented for conservative treatment of symptoms. Patients with the following characteristics were excluded: paralysis, astasia, dementia, spinal cord tumor, spinal infection, and patients with a history of spinal surgery.

All patients were assessed by an orthopedic surgeon before entering the study. The assessment measures were performed by an experienced doctor and physiotherapist. We measured each subject's height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg).

Back muscle strength was determined from the maximum isometric strength of the trunk muscles in a sitting posture with 30° lumbar extension using a digital muscle strength meter (Isoforce GT-300, 310; OG GIKEN Co., Ltd., Okayama, Japan). Data analysis was performed using SYNAPSE (Fujifilm Medical Co., Ltd., Tokyo, Japan), an area calculation software program used to measure the erector spinae muscle and lumbar multifidus cross-sectional area at L1/2 and L4/5 by magnetic resonance imaging (MRI). The L1/2 and L4/5 lumbar multifidus cross sectional area ratio was calculated as (lumbar multifidus cross sectional area) / (lumbar multifidus cross sectional area + erector spinae muscle cross sectional area) ×100. The regional body composition was measured using dual-energy X-ray absorptiometry (DXA) (Lunar DPX, Madison, WI, USA). Appendages were isolated from the trunk and head using a DXA regional computer-generated default line. Appendicular skeletal muscle mass (ASM) was derived as the sum of the fat-free soft tissues or fat tissue of the arms and legs. The skeletal muscle mass index (SMI) was calculated as ASM/height^2. The sagittal vertebral axis (SVA) has also been proposed as a criteria of sagittal alignment[6]. The SVA is defined as the horizontal offset from the posterosuperior corner of S1 to the vertebral body of C7. The SVA was measured using SYNAPSE (Fujifilm Medical Co., Ltd., Tokyo, Japan). All participants were asked to complete a pain questionnaire. Pain was assessed using the Roland–Morris disability questionnaire (RDQ)[7].

The center of pressure (COP) was recorded using a balance board (Wii; Nintendo Co., Ltd., Kyoto, Japan)[8, 9]. A vibratory stimulus was applied alternately to two muscles by fixing two vibrators from the vibration device onto the participant's gastrocnemius (GS) and lumbar multifidus (LM) muscle. The subjects stood barefoot on the balance board with their feet together and their eyes closed. They were instructed to remain still and relax in the standing position with their arms hanging loosely at their sides. Each subject's COP was measured under four conditions: the two muscles × two frequencies of vibratory stimulation: (1) 60-Hz on GS, (2) 60-Hz on LM, (3) 240-Hz on GS, and (4) 240-Hz on LM. The measurement time was 30 s, which was divided into two intervals of 15 s each. Vibratory stimulation was applied to the participants during the last 15 s. We labeled the first 15 s as "Pre" and the last 15 s as "During." The participants rested on a chair for 60 s between measurements. To provide additional information regarding proprioceptive dominance, the relative proprioceptive weighting ratio (RPW) was calculated using the following equation: RPW=(Abs GS)/(Abs GS + Abs LM) ×100 [%], where Abs GS and Abs LM are the absolute values of the mean COP displacement during GS and LM vibrations, respectively[10, 11]. We defined the change in anteroposterior displacement of the COP as follows: $\Delta Y = Y\ (\text{During}) - Y\ (\text{Pre})$, where Y is the displacement of the Y-coordinate of the COP recorded by the balance board and Y (Pre) and Y (During) are the mean values of the time series of Y data for the first and last 15 s, respectively. These values were calculated using Matlab (MathWorks, Inc., Natick, MA, USA)[12] in a blinded manner regarding the presence of LBP.

The data were analyzed using the Statistical Package for Social Sciences version 19.0 for Windows (SPSS Inc., Chicago, IL, USA). P<0.05 was considered statistically significant. Data are expressed as mean values with standard deviations. Variable data for LBP and NLBP were compared using the independent t-test. Multiple regression analysis was performed using stepwise method adjusted for several confounding factors (significant variables in t-test) of LBP and NLBP, and confirmed that there was no significant difference. Logistic regression analysis, performed as a stepwise analysis, was conducted to examine whether the RPW was independently associated with LBP.

RESULTS

Table 1 shows the demographic and baseline clinical characteristics of the study participants. Compared with NLBP controls, older persons with LBP showed a lower RPW 240-Hz (p<0.05), lower L4/5 lumbar multifidus cross section area ratio (p<0.01), significantly older age (p<0.01), and higher RDQ (p<0.05) (Table 1, 2). Table 3 shows the factors associated

Table 1. Demographic characteristics and functional outcomes of the subjects

Variables	All Subjects (n=111)	LBP (n=47)	NLBP (n=64)
Age (years)	75.0 ± 4.8	76.7 ± 4.2 **	73.8 ± 4.9
Gender (men)	65 (58.6)	25 (53.1)	40 (66.7)
Height (cm)	156.5 ± 8.9	154.9 ± 9.3	157.7 ± 8.4
Weight (kg)	60.4 ± 11.4	59.5 ± 11.8	61.1 ± 11.2
Back muscle strength (N)	163.4 ± 39.4	155.0 ± 35.2	169.5 ± 41.4
L1/2 lumbar multifidus cross section area ratio (%)	10.0 ± 2.4	10.3 ± 2.3	9.8 ± 2.5
L4/5 lumbar multifidus cross section area ratio (%)	33.4 ± 7.93	31.1 ± 8.5 **	35.0 ± 7.1
SMI (kg/m^2)	6.8 ± 1.1	6.6 ± 1.2	6.8 ± 1.0
SVA (mm)	49.4 ± 34.1	56.1 ± 28.9	44.5 ± 36.9
RDQ (score)	10.7 ± 5.3	12.1 ± 5.1 *	9.6 ± 5.2

LBP: low back pain; NLBP: non-low back pain; Underlined %: cells with significant adjusted standardized residuals; SMI: skeletal muscle mass index; SVA: sagittal vertical axis; RDQ: Roland-Morris disability questionnaire.
Data are presented as the mean ± SD or n (%).
All p-values were generated using the independent t-test.
*p<0.05, **p<0.01

Table 2. Mean Relative Proprioceptive Weighting (RPW) values with standard deviations (SD) for postural stability trials while standing on a balance board

Variables	All Subjects (n=111)	LBP (n=47)	NLBP (n=64)
RPW 60-Hz (%)	52.3 ± 24.1	52.3 ± 23.0	52.2 ± 25.0
RPW 240-Hz (%)	51.3 ± 26.4	44.7 ± 25.9 *	56.1 ± 25.9

LBP: low back pain; NLBP: non-low back pain; RPW: relative proprioceptive weighting values.
Data are presented as the mean ± SD.
All p-values were generated using the independent t-test.
Results of the RPW values of the standing trials: lower RPW 240-Hz-values indicate more reliance on trunk muscle proprioceptive inputs in people with LBP under both standing conditions.
*p<0.05

Table 3. Factors associated with LBP in stepwise logistic regression

Variables	OR	95% CI
Age (years)	1.14 **	1.05–1.25
RPW 240-Hz (%)	0.98 *	0.97–0.99

OR: odds ratio; CI: confidence interval; LBP: low back pain; RPW: relative proprioceptive weighting ratio.
*p<0.05, **p<0.01

with LBP in stepwise logistic regression. Logistic regression analysis showed that classification to RPW 240-Hz (odds ratio [OR], 0.98; 95% confidence interval [CI], 0.97–0.99; p<0.05) was independently associated with LBP accounting for the following confounding factors: age (OR, 1.14; 95% CI, 1.05–1.25; p<0.01). The model was well calibrated between declines of observed and expected risk (Hosmer Lemeshow χ^2=5.4, p=0.71) (Table 3).

DISCUSSION

We found that after 240-Hz vibratory stimulus, patients with LBP decreased their reliance on proprioceptive signals from the lower leg when standing. However, this decline in sensitivity was not apparent at RPW 60-Hz. Therefore, those in the LBP group tended to display greater sway during 240-Hz vibratory stimulation of the trunk than the NLBP controls. In addition, trunk predominance during RPW 240-Hz was demonstrated as a risk factor for instability in the LBP group.

Meanwhile, despite the evaluation of trunk function using SVA and RDQ variables, only a trunk-steered proprioceptive control strategy and old age were identified as a clear risk factor for developing LBP. Previous studies have reported that proprioception and vibration sensation in the lower limbs decrease during normal aging[13, 14]. In addition, high frequency vibration stimulates Type II fast-adapting skin receptors, known as Vater-Pacini corpuscles[15]. Further, other studies have reported the consistently reduced anteroposterior shear force in the LBP group may indicate their difficulty in producing or controlling a hip strategy[16]. According to previous studies, while the hip and ankle strategies are stereotypical, a continuum of mixed strategies is used under most circumstances[16], and factor of decision on predominance of strategy is made depending on experience, expectation of the perturbation, and environmental constraints[17, 18]. Therefore, based on the RPW with 240-Hz stimulation, LBP with lumbar spondylosis appears to be influenced by reduced of ankle strategy caused by the decreased vibratory sensation rather than by touch sensation. Previous studies have reported that proprioception and vibration sensation in the lower limbs decrease during normal aging[13, 14], and postural instability has been observed in older persons[19].

Therefore, patients with LBP may have even greater postural instability as the sensitivity of GS continues to decline. Taken together, the reduction in RPW with 240-Hz stimulation regarding lower leg proprioception suggests an inability of these patients with LBP to switch to a more appropriate proprioceptive postural control strategy, possibly causing postural instability. The tendency toward an unstable postural sway with reduced lower leg sensitivity in patients with LBP was in line with our hypothesis regarding the high frequency vibration. Therefore, higher frequency vibratory testing for muscle may provide a more sensitive clinical test of proprioception loss in this population.

Accordingly, relying on LM proprioceptive signals to control posture may lead to a risk of postural instability, with the decreased proprioceptive signals adapting to high frequency vibratory stimulations in older persons of LBP.

A limitation of this study is that only older persons with lumbar spondylosis were surveyed. Therefore, additional studies with healthy older persons and those with more severe disability must be conducted. Despite the evaluation of the proprioceptive system by means of muscle vibration, it remains unclear whether these proprioceptive control changes are based on peripheral inputs reduction at LBP. Finally, additional study using RPW (Vater-Pacini corpuscles) in combination with neurological examination during postural control assessment may help to answer this question.

Conflict of interest

None.

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