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Relationship between paraspinal muscle cross-sectional area and relative proprioceptive weighting ratio of older persons with lumbar spondylosis

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Abstract. [Purpose] The purpose of this study was to examine the relationship between the paraspinal muscle cross-sectional area and the relative proprioceptive weighting ratio during local vibratory stimulation of older persons with lumbar spondylosis in an upright position. [Subjects] In all, 74 older persons hospitalized for lumbar spondylosis were included. [Methods] We measured the relative proprioceptive weighting ratio of postural sway using a Wii board while vibratory stimulations of 30, 60, or 240 Hz were applied to the subjects' paraspinal or gastrocnemius muscles. Back strength, abdominal muscle strength, and erector spinae muscle (L1/L2, L4/L5) and lumbar multifidus (L1/L2, L4/L5) cross-sectional areas were evaluated. [Results] The erector spinae muscle (L1/L2) cross-sectional area was associated with the relative proprioceptive weighting ratio during 60Hz stimulation. [Conclusion] These findings show that the relative proprioceptive weighting ratio compared to the erector spinae muscle (L1/L2) cross-sectional area under 60Hz proprioceptive stimulation might be a good indicator of trunk proprioceptive sensitivity.

Key words: Relative proprioceptive weighting ratio, Erector spinae muscle cross-sectional area, Older persons with lumbar spondylosis

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INTRODUCTION

An upright posture requires postural control stabilization, which is essential for activities of daily living of older persons and younger people. The central nervous system must identify and selectively focus on the sensory proprioceptive inputs that functionally provide the most reliable signals[1]. After processing of the sensory inputs, individuals must integrate the respective contributions of the various sources of sensory information for regulating posture. Hay et al.[2] reported that older persons have difficulties in taking advantage of sensory redundancy in postural control. In addition, a defect or slowing of this mechanism has been suggested to explain the difficulties experienced by older persons when trying to control their posture[3, 4]. Proprioceptive input from the muscles of the legs and trunk plays an important role in maintaining postural stability[5].

Previous studies have reported that proprioception and vibration sensation in the lower limbs decreases during normal aging, and that postural instability occurs in older persons[6]. Therefore, a vibratory stimulus that matches the response frequency of the receptors present in skeletal muscle may influence postural stability and trunk mobility. The representative receptor and response frequencies are 30 Hz in Meissner's corpuscles, 60 Hz in muscle spindles, and 240 Hz in Vater-Pacini corpuscles[7].

Previous studies have reported that patients with recurrent low back pain (LBP) have impaired motor control[8] and altered lumbosacral proprioceptive acuity[9, 10]. LBP is a widespread pathological condition that is often related to impaired or degenerated trunk mobility, which becomes evident during common activities[11, 12]. Taimela et al.[13] reported that lumbar muscle fatigue impaired lumbar positional sense in both patients with LBP and healthy subjects. Therefore, the postural control of older persons with lumbar spondylosis might be negatively influenced by a decline in the paraspinal muscle cross-sectional area, causing proprioceptive decline. However, the specific receptor mechanisms that explain this decline in paraspinal muscle cross-sectional area and postural instability in older persons with lumbar spondylosis are

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*Corresponding author. Tadashi Ito (E-mail: 13s3008@g.iuhw.ac.jp) not yet clear. Additionally, little is known about the relationship between the paraspinal muscle cross-sectional area and the adaptive proprioceptive response to changing vibratory stimulations. To our knowledge, no previous studies have examined the possible relationship between a decline in the cross-sectional area of each paraspinal muscle (L1/L2 and L4/L5 erector spinae muscles and L1/L2 and L4/L5 lumbar multifidus) and the proprioceptive response in older persons with lumbar spondylosis.

The aim of the present study was to determine how paraspinal muscle cross-sectional area decline is related to the proprioceptive postural control strategy for balance control while standing upright in older persons with lumbar spondylosis.

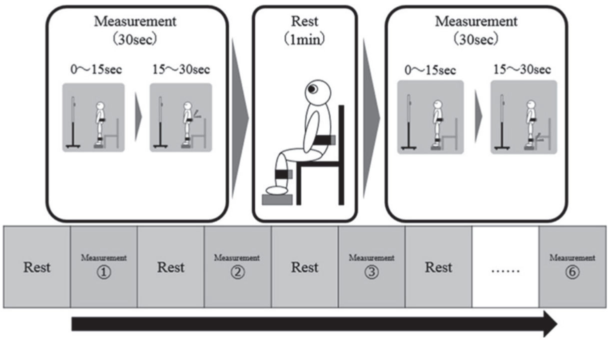

Fig. 1. Patients, with eyes closed, stood on a force plate while the gastrocnemius muscles and lumbar muscles were subjected to vibration

SUBJECTS AND METHODS

This study was carried out over a 1 year and 11 months period (Nov in 2012 to Sep in 2014) in general practice. Written informed consent was obtained from all participants prior to 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 at the Graduate School of the International University of Health and Welfare approved the study. In total, 74 older (≥65 years) persons with lumbar spondylosis who were admitted to the National Hospital for Geriatric Medicine were recruited for the study. We measured each subject's height (to the nearest 0.1 cm) and weight (to the nearest 0.1 kg). The study subjects were patients with spinal column stenosis and spondylitis deformans who presented for conservative treatment of symptoms. Additional inclusion criteria were the ability to perform the task and the absence of severe neuromuscular or orthopedic disease, spinal tumors, or infection. All patients were assessed by an orthopedic surgeon before entering the study.

The assessment measures were performed by an experienced doctor and physiotherapist. The assessment included some physical tests. The center of pressure (CoP) was recorded using a balance board (Wii; Nintendo Co., Ltd., Kyoto, Japan)[14–17]. A vibratory stimulus was delivered alternately to two muscles by fixing two vibrators from the vibration device on the participants' lumbar and gastrocnemius muscles. The vibration device has been developed in our previous work. The device consists of a laptop computer, an audio amplifier, four vibrators. A sine wave signal with an arbitrary frequency generated on the laptop computer is input to the audio amplifier. The range of displacement of the vibrators is 0–0.8 mm, and the frequency range is 30–400 Hz. Mechanical vibration is a commonly used method to test externally induced balance control, and it has been widely used to analyze the role of proprioception in the control of postural sway[18–22]. The subjects stood barefoot on the Wii Balance Board with their feet together and their eyes closed. They were instructed to remain still and relax in the standing posture with their arms hanging loosely at their sides. The amplitude of the vibration was 1.6 mm (peak to peak) of sinusoidal motion with frequencies of 30, 60, and 240 Hz. Each subject's CoP was measured under six conditions: the two muscles × three frequencies of vibratory stimulation (Fig. 1): (1) 30 Hz on lumbar muscles, (2) 30 Hz on gastrocnemius muscles, (3) 60 Hz on lumbar muscles, (4) 60 Hz on gastrocnemius muscles, (5) 240 Hz on lumbar muscles, and (6) 240 Hz on gastrocnemius muscles. The measurement time was 30 s, which was divided into two intervals of 15 s each. The 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 about proprioceptive dominance, a relative proprioceptive weighting (RPW) ratio was calculated using the following equation: RPW = (Abs GM)/(Abs GM + Abs LM) × 100, where Abs GM is the absolute value of the mean CoP displacement during gastrocnemius muscle vibration and Abs LM is the absolute value of the mean CoP displacement during lumbar muscle vibration. An RPW ratio of 1 corresponds to 100% reliance on GM input ("lower limb-focused strategy"), whereas an RPW ratio of 0 corresponds to 100% reliance on LM input ("multisegmental strategy")[23–25].

Data extraction was performed using SYNAPSE® (Fujifilm Medical Co., Ltd., Tokyo, Japan), an area calculation software used to measure the erector spinae muscle and lumbar multifidus cross-sectional area at L1/L2 and L4/L5 by magnetic resonance imaging (MRI). The participants were placed in the neutral position (supine posture with knees extended and hands lying across their abdomen) on the MRI table. Scans were obtained perpendicular to the MRI table at transverse levels through the approximate centers of the vertebral bodies from L1 to L5. The MRI scans of the erector spinae muscle and lumbar multifidus cross-sectional area were assessed by an orthopedic surgeon. Back and abdominal muscle strength was determined from the maximum isometric strength of the trunk muscles in a sitting posture with 30° lumbar extension (back muscle strength) or 30° lumbar flexion (abdominal muscle strength) using a digital muscle strength meter (Isoforce GT-300, 310; OG GIKEN Co., Ltd., Okayama, Japan). 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 Wii 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 calculations were performed using a program we wrote using Matlab (MathWorks, Inc., Natick, MA, USA)7). Multiple linear regression analysis was used to examine whether the RPW ratio was associated with back strength, abdominal muscle strength, erector spinae muscle (L1/L2, L4/L5) cross-sectional area, or lumbar multifidus (L1/L2, L4/L5) cross-sectional area. Pearson's correlation coefficient was used to determine the relationships among back muscle strength, abdominal muscle strength, erector spinae muscle (L1/L2, L4/L5) cross-sectional area, and lumbar multifidus (L1/L2, L4/L5) cross-sectional area. Significant correlative variables (e.g., back muscle strength, abdominal muscle strength, erector spinae muscle [L1/L2, L4/L5] cross-sectional area, and lumbar multifidus [L1/L2, L4/L5] cross-sectional area) were set as the dependent variables. Independent variables included the RPW ratios at 30, 60, and 240 Hz. RPW ratios at 30, 60, and 240 Hz were also investigated using stepwise multiple linear regression analysis. All analyses were performed using IBM SPSS statistical software (Version 19.0; IBM Corp., Armonk, NY, USA). Statistical significance was accepted for values of $p < 0.05$.

Table 1. Physical characteristics of the study participants (N = 74)

Variables	Data (mean ± SD)
Age (years)	74.4 ± 5.3
Height (cm)	155.7 ± 8.2
Weight (kg)	58.5 ± 10.9
RPW at 30 Hz (%)	52.5 ± 26.7
RPW at 60 Hz (%)	56.7 ± 24.6
RPW at 240 Hz (%)	56.5 ± 25.0
Back muscle strength (N)	171.2 ± 42.8
Abdominal muscle strength (N)	119.1 ± 37.0
Erector spinae muscle (L1 / L2) cross-sectional area (mm^2)	2,722.4 ± 714.9
Erector spinae muscle (L4 / L5) cross-sectional area (mm^2)	1,845.6 ± 493.7
Lumbar multifidus (L1 / L2) cross-sectional area (mm^2)	314.9 ± 84.3
Lumbar multifidus (L4 / L5) cross-sectional area (mm^2)	987.1 ± 322.0

RPW: relative proprioceptive weighting ratio

RESULTS

The characteristics of the subjects are shown in Table 1. Table 2 shows that the erector spinae muscle (L1/L2) cross-sectional area was significantly negatively associated with the RPW ratio at 60Hz stimulation. Additionally, the erector spinae muscle (L1/L2) cross-sectional area was significantly negatively associated with the RPW ratio at 60Hz stimulation ($\beta = -0.26$, $p < 0.05$). There was no significant relationship between the RPW ratio and back muscle strength or abdominal muscle strength at this level of proprioceptive stimulation (RPW ratio with 30, 60, or 240Hz stimulation). There was also no significant relationship between the erector spinae muscle (L4/L5) cross-sectional area and the RPW ratio at 30, 60, or 240Hz stimulation. Finally, there was no significant relationship between the lumbar multifidus (L1/L2, L4/L5) cross-sectional area and the RPW ratio at 30, 60, and 240Hz stimulation.

DISCUSSION

The main result of this study of proprioceptive postural control is that older persons with lumbar spondylosis showed a relationship (beyond that of just muscle strength) between the erector spinae muscle (L1/L2) cross-sectional area and the RPW ratio at 60Hz stimulation. Additionally, the results suggest that the RPW ratio at 60Hz elicits different responses according to the cross-sectional area of each trunk muscle. Thus, a reduced erector spinae muscle (L1/L2) cross-sectional area may induce changes in muscle spindles, thereby changing the proprioceptive postural strategy. These problems probably increase dependency on proprioceptive information from the lower limb rather than the trunk because of the reduced muscle spindle response.

Recent studies in which a vibratory stimulation of 60 Hz was used have suggested that people with LBP adopt a lower leg-derived postural control strategy26, 27). A possible explanation is that these participants were exploiting this strategy to its maximum effect during vibratory stimulation of 60 Hz. Another possible explanation is that the erector spinae muscle (L1/L2) cross-sectional area needed to stabilize the spine is decreased, which might lead to a reduced multisegmental control strategy28). The erector spinae muscle (L1/L2) cross-sectional area may be important for stabilizing posture in older persons with lumbar spondylosis, and should not be ignored.

It is likely that older persons with lumbar spondylosis compensate for disturbances in balance using a lower leg-derived steered postural control strategy instead of an erector spinae muscle (L1/L2)-derived postural control strategy. Taken together, these data suggest that balance is determined not only by motor output, but also by the contribution and central processing of sensory inputs from the erector spinae muscles.

When the function of the erector spinae muscle is impaired, deficits occur in both the motor and sensory aspects of balance. However, the correlation between the erector spinae muscle (L1/L2) cross-sectional area and the RPW ratio at 60Hz stimulation was very weak. In contrast, the RPW ratio at 60Hz was not significantly correlated with the any other cross-sectional area of the muscle, except with the erector spinae muscle (L1/L2) cross-sectional area. Quantitative assessment of proprioceptive sensitivity might be difficult using only the RPW ratio because 60Hz stimulation might not reach the deep muscle layer. This suggests that the variable derived from the RPW ratio at 60 Hz is not the only index for assessment of a proprioceptive sensitivity decrease in the back muscles. In the present study, however, a smaller erector spinae muscle (L1/L2) cross-sectional area was associated with a greater change in the RPW ratio at 60 Hz. The results of RPW testing show that older persons with lumbar spondylosis adopt an erector spinae muscle (L1/L2)

Table 2. Correlation coefficients between each RPW, back muscle strength, abdominal muscle strength, erector spinae muscle (L1/L2, L4/L5) cross-sectional area, and erector spinae muscle (L1/L2, L4/L5) cross-sectional area (N = 74)

Variables	RPW at 30 Hz	RPW at 60 Hz	RPW at 240 Hz	Back muscle strength	Abdominal muscle strength	Erector spinae muscle (L1 / L2) cross-sectional area	Erector spinae muscle (L4 / L5) cross-sectional area	Lumbar multifidus (L1 / L2) cross-sectional area	Lumbar multifidus (L4 / L5) cross-sectional area
RPW at 30 Hz	—	0.227	−0.102	0.007	−0.177	0.048	0.019	−0.033	0.113
RPW at 60 Hz	0.227	—	−0.031	−0.162	−0.129	−0.260*	−0.086	−0.183	−0.007
RPW at 240 Hz	−0.102	−0.031	—	0.081	0.162	0.171	0.205	−0.019	0.130
Back muscle strength	0.007	−0.162	0.081	—	0.691**	0.565**	0.187	0.401**	0.375**
Abdominal muscle strength	−0.177	−0.129	0.162	0.691**	—	0.621**	0.338**	0.388**	0.392**
Erector spinae muscle (L1 / L2) cross-sectional area	0.048	−0.260*	0.171	0.565**	0.621**	—	0.562**	0.558**	0.567**
Erector spinae muscle (L4 /L5) cross-sectional area	0.019	−0.087	0.205	0.187	0.338**	0.562**	—	0.249*	0.256*
Lumbar multifidus (L1 / L2) cross-sectional area	−0.033	−0.183	−0.019	0.408**	0.388**	0.558**	0.249*	—	0.439**
Lumbar multifidus (L4 / L5) cross-sectional area	0.113	−0.007	0.130	0.375**	0.392**	0.567**	0.256*	0.439**	—

RPW: relative proprioceptive weighting ratio. Pearson's correlation coefficient *p < 0.05; **p < 0.01.

response at 60 Hz, and that their back muscle proprioception may decrease.

The results of this study have some clinical implications. Our findings suggest that decreased trunk muscle proprioception (from muscle spindles) may increase reliance on proprioceptive information from the lower leg during vibratory stimulation in the upright position. Accordingly, reliance on the gastrocnemius muscle proprioceptive signals (multisegmental control strategy) to control posture may lead to a decrease in trunk proprioceptive signals, with the decreased erector spinae muscle (L1/L2) cross-sectional area adapting to 60Hz vibratory stimulations.

A limitation of this study was that only older persons with lumbar spondylosis were surveyed. Therefore, additional studies involving healthy older persons and those with other disabilities must be conducted. The proprioceptive signal response might show other changes during longer time intervals. For pragmatic reasons, the measurements were not randomized. Despite the short rest time between measurements, learning effects and fatigue cannot be ruled out as factors affecting the results.

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