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Postural stability and trunk muscle responses to the static and perturbed balance tasks in individuals with and without symptomatic degenerative lumbar disease

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ABSTRACT

Background: Degenerative lumbar diseases (DLDs) are characterized by motor functional deficits and postural instability. In this study, we investigated the differences in the trunk muscle responses to postural control between the presurgical DLD patients and healthy individuals while performing the static and perturbed balance tasks.

Methods: Thirty-five DLD patients (aged 61.1 ± 8.0 years) and thirty-five asymptomatic controls (aged 62.9 ± 3.7 years) participated in this study. All participants stood on a force plate and performed the quiet standing (QS) and in situ weight-lifting (WL) tasks. The participants' performance in the QS task was tested under the eyes-open, eyes-closed, wide-base, and narrow-base conditions. Center of pressure (CoP) movements and electromyography of the erector spinae (ES) were recorded. The Mann–Whitney *U* test was applied for statistical analysis.

Results: The DLD group showed a significantly greater CoP movements and muscle activations during the QS task. Nevertheless, smaller CoP movements were noted during the WL task in the DLD group. Under the eyes-closed and narrow-base conditions, the DLD group showed even higher muscle activations and CoP movements.

Significance: The DLD patients demonstrated a poor postural control ability and tended to rely on the visual feedback and wide-base standing posture. A rigid and restricted posture was also adopted during the perturbed WL task. A high level of ES activation was required to maintain their postural steadiness. This study reveals an aberrant pattern of postural control and trunk muscle activations in symptomatic DLD patients which potentially contributes to the development of beneficial rehabilitation programs.

1. Introduction

Degenerative lumbar diseases (DLDs) are common among the elderly adults. As defined by the Swedish Spine register [1,2], DLDs include degenerative disc disease, disc herniation, spinal stenosis, and lumbar spondylolisthesis. Studies have reported that the lumbar spine exhibits 16% degeneration in the third decade of life and up to 98% degeneration in the eighth decade of life. Furthermore, because of the increase in human life span, an increasing numbers of patients with DLDs may cause substantial socioeconomic burdens globally [3].

DLDs are associated with compromised structure and function that significantly reduce the range of motion and movement velocity of the lumbar spine [4]. With the development of neurological damages to the spinal nerves, restricted functional activities and reduced postural

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control abilities clinically manifest from the deviated motor control and pain-related changes in the lower limbs and lower back [5,6]. Patients with DLDs have shown to exhibit an increased postural sway measured by the changes of center of pressure (CoP) excursion during the quiet standing task [7,8]. And the impaired ability of the postural control is usually linked to the increased fall incidence observed in those patients [9,10]. They further showed a dynamic postural instability which could be presented as the gait disorders, such as low walking velocity and short strides [11]. Recurrent low back pain is also evidenced to result in the dysfunction of trunk muscles, such as decreased muscle strength, particularly in the extensor group [12,13]. However, up to date, whether pain alters the trunk muscle activations so as to affect the postural control strategy in patients with DLDs remains unclear. Thus it is worthy of study to examine their postural steadiness and muscle activations at the same time during various functional balance tasks and the results could help to facilitate the development of the training programs.

Lumbar surgery is recommended when conservative treatment fails to resolve recurrent low back pain and dysfunction in patients with DLDs [14]. Patients with DLDs who are eligible for lumbar surgery mostly experience moderate to severe pain in the legs and back, which limits the walking distance, restricts their functional capacity, and adversely affects their quality of daily activities [15]. Thus far, only rapid presurgical assessments, such as the subjective pain scale or questionnaire, have been reported to reveal functional changes in patients with DLDs. Objective examination to document the severity of the functional restrictions is rare and warrants investigation.

In this study, the differences in trunk muscle responses to postural control while performing the quiet standing (QS) task and in situ weight-lifting (WL) task, i.e. the static balance and internally perturbed balance tests separately, between the healthy individuals and presurgical patients with DLDs were investigated. The results will enhance the understanding of postural control strategies and provide reference for setting rehabilitation goals for the symptomatic patients with DLDs who are eligible for lumbar surgery.

2. Method

2.1. Participants

Patients with DLDs were recruited if they were aged between 40 and 80 years old, had received diagnoses of lumbar spondylosis or radiculopathy through magnetic resonance imaging (MRI), and had been scheduled for lumbar fusion surgery by orthopedic surgeons. Patients were excluded if they had traumatic spinal injury; medical systemic diseases that result in arthritis such as the ankylosing spondylitis, rheumatoid arthritis, and multiple sclerosis; any type of tumor; or psychiatric disorders or neurological diseases such as depression, delirium, chorea, and Down syndrome. The patients with DLDs were asked to quantify the level of pain by filling out the visual analog scale (VAS, 0–10) questionnaire. They also filled out the Oswestry Disability Index (ODI) questionnaire, which has sufficient reliability and validity to enable quantification of the functional disabilities of lumbar function in daily life [16–18]. This study also included a control group of healthy age-matched asymptomatic elderly individuals who did not experience pain in the lower back or lower limbs within the last year and had not undergone any surgery affecting their balance control. Patients with body mass index (BMI) > 31 kg/m^2 and chronic neurological or musculoskeletal diseases that might cause impaired balance were also excluded. The institutional medical research ethics committee approved this study. All the participants were unpaid volunteers, and they all provided written informed consent before their inclusion in the study.

2.2. Instrumentation

The trunk isometric strength was measured using a handheld dynamometer (MicroFET2, HOGGAN Health Industries, Inc., UT, USA) by using the manual muscle testing technique. A surface wireless electromyograph (EMG) system (Trigno Wireless System, Delsys Inc., Boston, USA) was used to record muscle activation levels while performing the experimental tasks. Before the placement of the EMG sensors, the skin hair was shaved and the skin was cleaned using alcoholic swabs for ensuring good-quality detection based on the Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines. For the measurement of activation levels of the erector spinae (ES), the major trunk extensor muscle group, the electrode sensors were placed bilaterally at a lateral distance of 4 cm from the L3 spinous process. The sampling rate of the EMG was 1 kHz, and the acquired data were digitally band-pass filtered between 20 Hz and 450 Hz, full-wave rectified, and smoothed using a low-pass filter (time constant of 100 ms; Butterworth eight order). The postural stability of participants during the experimental tasks was measured using a stationary force plate (Kistler 9260AA6, Kistler Instrumente AG, Winterthur, Switzerland). The EMG system and force plate were synchronized using the 32-channel 16-bit A/D board (NI USB-6218, National Instruments co., USA).

2.3. Experimental procedure

At the beginning of the experiment, the isometric maximal voluntary contractions (MVCs) of the trunk flexor and extensor were performed [19]. The trunk flexion isometric strength was measured when the participants were asked to take a supine position on the treatment table, with arms crossed over the chest and legs extended along the table. The examiner then applied body weight pressing down on the shoulders of the participants, who were asked to flex their upper trunk to bring the shoulders up off the table against the manual resistance for 5 s. The trunk extension isometric strength was measured when the participants were in a prone position with the arms alongside the legs but off the table. The examiner applied body weight pressing down on the shoulders of the participants who attempted to extend the upper trunk with shoulder retracted against the resistance of the examiner for 5 s. Participants were encouraged to exert their maximal force and were asked to keep breathing during each trial. Three repetitions were performed for each task with a 2-minute interval for recovery between repetitions. The participants were asked to indicate the VAS again after performing the MVC tests.

The participants were then asked to perform the stepping task, which indicated the strength and balance function of their lower extremities. They stood upright with the forearm crossed over the chest and started to flex the hip and knee joint to 90° reciprocally as fast as they could in situ for 10 s. Three repetitions were performed and the number of stepping was recorded. After sufficient rest, the performance of the participants in two types of functional tasks, the static and perturbed balance tasks, was examined.

The first functional task was the QS task that required the participants to stand still on the force plate with both hands placed comfortably on the thighs for 40 s. Four standing conditions were tested: eyes open and standing with a shoulder-width base (EOW), eyes closed and standing with a shoulder-width base (ECW), eyes open and standing with a narrow-base standing to close their feet together (EON), and eyes closed and a narrow-base standing (ECN). Second, the WL task required the participants to complete the WL trials with exclusively upper-extremity movements in an upright posture. The participants stood on the force plate with a shoulder-width base in front of a 90-cm-high table. A solid box weight of 6 kg was placed on the table. Upon receiving a verbal cue, the participants held the box and lifted it up to the height of chest, held the position for 3 s, and then lowered it back on the table. Between each trial, the participants were allowed to rest for minimizing fatigue. Three repetitions were recorded, and average values from the three repetitions were used in the statistical analysis.