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The role of trunk muscles in sitting balance control in people with low back pain ☆

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ABSTRACT

The purpose of this study was to examine the muscular activities and kinetics of the trunk during unstable sitting in healthy and LBP subjects. Thirty-one healthy subjects and twenty-three LBP subjects were recruited. They were sat on a custom-made chair mounted on a force plate. Each subject was asked to regain balance after the chair was tilted backward at 20°, and then released. The motions of the trunk and trunk muscle activity were examined. The internal muscle moment and power at the hip and lumbar spine joints were calculated using the force plate and motion data. No significant differences were found in muscle moment and power between healthy and LBP subjects ($p > 0.05$). The duration of contraction of various trunk muscles and co-contraction were significantly longer in the LBP subjects ($p < 0.05$) when compared to healthy subjects, and the reaction times of the muscles were also significantly reduced in LBP subjects ($p < 0.05$). LBP subjects altered their muscle strategies to maintain balance during unstable sitting, but these active mechanisms appear to be effective as trunk balance was not compromised and the internal moment pattern remained similar. The changes in muscle strategies may be the causes of LBP or the result of LBP with an attempt to protect the spine.

1. Introduction

It has been suggested that the main factors contributing to the stability of the trunk are the intrinsic passive stiffness of its structures and the active contraction of the muscles and that these factors are modulated by the neural system (Crisco and Panjabi, 1991; Gardner-Morse and Stokes, 2001; Panjabi, 1992). Moreover, co-contractions of trunk muscles are present to stabilise the spine during several activities (Granata and Wilson, 2001; Cholewicki et al., 1997). Panjabi (1992) proposed that an alteration of the passive structures may be related to a decrease in the intrinsic stiffness that can then lead to increased muscular activity as a compensatory response in order to sustain the stability of the trunk. This was confirmed by several studies which revealed evidence of increased activities of the trunk muscles due to low back pain (LBP) (Fischer and Chang, 1985; Pirouzi et al., 2006). Increased muscle co-contractions (Granata and Marras, 1995; Marras and Davis, 2001; Marras et al., 2004; Radebold et al., 2000) have also been observed, and may be related to increased spinal stress (Granata and Marras, 1995; Marras et al., 2004) that may lead to injuries and spinal degeneration (Adams et al., 1996; Gallagher et al., 2005).

Moreover, Shum et al. (2007b) studied the effects of back pain on the hip and spine moments during sit-to-stand. They showed that although the moment at the lumbar spine was decreased in the sagittal plane in LBP subjects, moments in transverse and frontal planes were increased. This was believed to be a compensatory strategy to reduce pain. Similar results were found also for the kinematic data of the trunk, where hip and lumbar spine motion patterns were found to be altered as a result of LBP (Shum et al., 2005a,b, 2007a).

The control of dynamic balance of the trunk is not fully understood. In comparison with the standing model used in previous studies (Cholewicki et al., 1997; Pirouzi et al., 2006; Sihvonen et al., 1991; Silfies et al., 2005), the present study employed a sitting position to study trunk balance as it would allow us to remove the influence of the legs and to study the role of the trunk in isolation.

The sitting position had been used by some previous authors to study the effects of LBP on trunk muscle activation. Radebold et al. (2000) and Radebold et al. (2001) measured the responses of trunk muscles to sudden perturbation, and found that the response time

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was delayed in LBP subjects. This might suggest that LBP might compromise the motor control mechanism of the spine. Van Dieen et al. (2003) also reported that the ratio of the EMG amplitudes of the antagonist to agonist muscles were increased in LBP patients. However, these previous studies did not examine how these muscle contractions counterbalance the external moment imposed on the spine. In this study, inverse dynamic analysis was used to determine the external moment, which would be correlated with the trunk muscle contraction pattern. In particular, muscle powers were analysed allowing us to evaluate the nature of the contractions, whether they were eccentric or concentric.

One limitation of the inverse dynamic model was that it did not allow us to study co-contraction of muscles which may be present during the perturbation (Granata and Marras, 1995; Marras et al., 2001, 2004; Radebold et al., 2000). In this study, such limitation was addressed by collecting EMG signals of the trunk muscles. The evaluation of any possible co-contraction would significantly increase our understanding of how various muscles contribute to the muscle moment and power. We also extended our inverse dynamic analysis to the hips so that we could evaluate the interaction between the spine and hip joint loads.

The purpose of this study was to examine the muscular activities and kinetics of the trunk during unstable sitting, and to determine the differences in these responses between healthy and low back pain (LBP) subjects. It was hypothesised that there would be differences between LBP and healthy subjects in moment and power distribution between hip and spine joints, and in trunk muscle activation patterns.

2. Methods

2.1. Subjects

Thirty-one healthy subjects without history of LBP and twenty-three subjects with sub-acute (>6 weeks) LBP (Savigny et al., 2009) were recruited for the study using advertisements in the University of Roehampton and in public locations near the university. Subjects' characteristics are summarised in Table 1. They were found not to be significantly different between LBP and healthy subjects ($p > 0.05$). Exclusion criteria for all subjects were the presence of ankylosing spondylitis, fractures/dislocations of the spine or hips, history of spinal or hip surgery, pregnancy, neurological disorders, cancer and osteoporosis. A visual analogue scale (VAS) was used to record the perceived severity of pain experienced by LBP and the functional ability evaluated by Oswestry Disability Questionnaire (Fairbank and Pynsent, 2000). LBP subjects were also asked to indicate where the pain was located (bilateral, left or right side). The study was approved by the Ethics Committee of the University of Roehampton. All subjects were asked to read and sign an informed consent form prior to the experiment.

Table 1
Subjects characteristics.

	Healthy subjects ($n = 30$) Mean ± SD	LBP subjects ($n = 24$) Mean ± SD
Age (yr)	31.73 ± 8.10	36.83 ± 11.56
Body height (m)	1.676 ± 0.980	1.689 ± 0.840
Body mass (kg)	63.89 ± 13.33	68.96 ± 11.64
BMI (kg/m^2)	22.53 ± 2.67	24.09 ± 3.09
Oswestry score (scale 0–100)	N/A	19.83 ± 8.94
VAS score (scale 0–10)	N/A	3.80 ± 1.02

N/A = not applicable.

2.2. Equipment

A custom-made chair (Fig. 1) was built which was restricted to swing in the sagittal plane. It had feet and leg support to restrict the knee and ankle to a 90° angle, and adjustable belts to restrict lower limb movements. The base of the chair was mounted onto a force platform (Type 9281B, Kistler™). The chair was built from wood, as metal would interfere with the electromagnetic field generated by the transmitter of the motion tracking system. The swinging mechanism was provided by two low friction ball bearing joints. Mechanical stops prevented the chair from tilting more than 20° backward and forward.

The movement of the lumbar spine was measured using a three-dimensional motion track system (3SPACE FASTRAK®, Polhemus Inc.) recording at 40 Hz. Two sensors were placed on the subjects' back, one at the sacrum level and one at the first lumbar vertebral level. One further sensor was placed on the chair to track its rotation, which was also used to define the rotation of the lower limbs. Integral dry reusable electromyographic (EMG) electrodes (Biometrics Ltd, type Nos. SX230) were connected to the DataLINK system (DLK900, Biometrics Ltd., Gwent, UK) to record the electrical activities of the paraspinal muscles at a sampling rate of 1000 Hz. The diameter of each electrode was 1 cm and interelectrode distance was 2 cm. The EMG signals were amplified using a single differential amplifier with an input impedance of 10^7 MΩ, a common mode rejection ratio of 110 dB, a gain of 1000 and a bandwidth 20–460 Hz. After skin preparation with alcohol and shaving of hair, the surface electrodes were secured with double-sided tape bilaterally on the erector spinae (3 cm lateral to the L3 spinous process), rectus abdominis, external and internal oblique (Thomas and Lee, 2000). Reference electrode was positioned over the left medial malleolus process. The chair was placed over the force platform recording at 150 Hz, in order to determine the loads that acted on the system formed by the chair and the subject. Measure Foundry (Data Translation Inc.) software was used to synchronize data acquisition of the devices and to integrate motion and force data. MATLAB® (R2007b, MathWorks Inc.) was used for data re-sampling and analysis and SPSS (SPSS: An IBM Company) was used for statistical analysis.

2.3. Protocol

Subjects were strapped to the chair with the lower limbs and pelvis immobilised, and they were asked to fold their arms across the chest facing forward. The height of the feet support was adjusted to allow the subject to sit in a comfortable position (Fig. 1). Initially, the subject was tilted twice backwards and forwards by the researcher in a controlled manner to show the range of motion (ROM) of the chair, and then the balanced position (with the chair parallel to the floor) was shown to the subject. Thereafter, the researcher tilted the chair into an angle between 0° and 20° and following release, the subject was asked to return to the balanced position and maintain it for 5 s. This familiarisation protocol ended when the subject was able to find the balanced position and to hold it for at least 5 s for three repetitions. All subjects were able to complete the familiarisation protocol. After the familiarisation protocol, the chair was tilted 20° backward. The chair was released without warning and they were asked to achieve the steady balanced position. All subjects were able to reach the balanced positions within three attempts. The average number of attempts of healthy and LBP subjects were 1.2 ± 0.3 and 1.5 ± 0.4, and there were no significant differences between the two groups ($p < 0.05$). Data collection was terminated after the first successful attempt and this data set was useful for the analysis. The trial was considered to be successful when the subject was able to reach a