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Muscle activity and kinetics of lower limbs during walking in pronated feet individuals with and without low back pain

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ABSTRACT

The objectives of this study were to investigate whether excessive feet pronation alters the joints' kinematics, kinetics and the activity of involved muscles during gait in low back pain patients. *Methods:* The lower limb joints' motion, moment and power, as well as the activity of involved muscles during walking were measured in a control group, and two experimental groups including a group with excessive feet pronation only, and another group of low back pain patients with excessive feet pronation. *Results:* In both experimental groups, ankle inversion, knee flexion and internal rotation, hip internal rotation, plantar flexors' moment, hip flexors' moment, and peak positive ankle power were lower than those in control group ($p < .05$). Besides, in patients, higher activity of gastrocnemius medialis, gluteus medius, erector spinae, and internal oblique muscles, and lower negative power at the ankle and peak positive power at the knee were observed ($p < .05$). In conclusion, pronated feet with low back pain was associated with less ankle inversion and knee flexion, higher knee and hip internal rotation, higher muscle activity, less energy absorption at the ankle, and reduced positive power at the knee. This study reveals that strengthening of the muscles especially knee extensors are of great importance in low back pain patients with feet pronation.

1. Introduction

Low back pain (LBP) is a common orthopedic ailment that afflicts up to 80% of the population at some point in their lifetime (Maetzel and Li, 2002; Pai and Sundaram, 2004; Walker et al., 2004). The annual treatment cost and economic burden of LBP exceed £14 billion in United Kingdom and $14.5 billion in the United States (Dagenais et al., 2008; Miyamoto et al., 2016; Walker et al., 2004). Although its etiology is still unknown, perturbed lower limbs dynamics are considered as risk factors. These include joints' rigidity, hip and lumbar muscle stiffness or weakness and poor postural muscle function leading to asymmetrical or abnormal mechanical loading of the lumbar spine (Chaléat-Valayer et al., 2011; Christe et al., 2016; Chuter and de Jonge, 2012; Gombatto et al., 2015; Jones et al., 2012).

Walking speed, pelvic rotation, and knee flexion at initial heel contact were reduced in chronic non-specific LBP patients (Müller et al., 2015). Reduced walking speed is postulated to be an adaptation to diminish vertical ground reaction force (GRF) and lumbar pain during walking (Müller et al., 2015). An increased activity of the erector spinae (Hanada et al., 2011; Lamoth et al., 2006) and hamstring (Vogt et al., 2003) muscles was also reported in LBP patients. Authors addressed the link between the transferred impact forces to the spine associated with running and the height of the longitudinal medial arch (Ogon et al., 1999), the pelvic tilt and subtalar pronation in walking (Betsch et al., 2011).

Altered foot structure can influence the lower limbs and pelvic alignment (Betsch et al., 2011; Khamis and Yizhar, 2007), erector spinae and gluteal muscles' activity (Bird et al., 2003), and lumbar spine kinematics (Ogon et al., 1999). Pronated foot (PF) in particular, is associated with internal rotation of the shank (Duval et al., 2010), and pelvic ipsilateral drop in weight-bearing during gait (Tateuchi et al., 2011). In addition, abnormal foot shape is related to knee osteoarthritis progression (Miyazaki et al., 2002). It is reasonable to assume that foot pronation is associated with LBP.

Different types of foot orthoses are prescribed for the treatment of chronic LBP. Possible rational for the use of foot orthoses is their ability to alter foot alignment, leading to kinematic postural changes of the lower limb and pelvis, as well as in the activity patterns of lower limb

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and pelvic musculature (Kendall et al., 2014).

The treatment of the postural abnormalities of the foot is included in the treatment procedure of LBP (Ball and Afheldt, 2002; Cambron et al., 2011; Castro-Mendez et al., 2013; Hsu et al., 2014; Papuga and Cambron, 2016; Shabat et al., 2005). This is justified since excessive foot pronation, and the elevated GRF were observed in individuals with low back pain (Farahpour et al., 2016). da Silva Azevedo et al. (2016) found that neuromuscular adaptations following four months bare foot running reduced the muscle activity of quadriceps, tibialis anterior, and gastrocnemius and the GRF in gait (da Silva Azevedo et al., 2016). It appears that muscle activation pattern is linked to GRF components in gait and should be considered when assessing LBP and its treatment.

Considering that GRF in gait is higher in PF with LBP (Farahpour et al., 2016), that excessive foot pronation imposes an axial rotation of tibia and femur, which could in turn modify the muscle action during gait, it is hypothesized that the neuromuscular response in some PF individual could be different in LBP patients. Nonetheless, it is unclear how the lower limbs' muscles activity in gait is linked with LBP and foot pronation. A better understanding of lower limbs' muscles activity during walking, and its relation to foot pronation could lead to a better understanding of the mechanism underlying LBP and its treatment.

In many investigations on LBP patients, the foot shape abnormalities are not addressed. Only Farahpour et al. (2016) investigated the GRF components in PF individuals with and without LBP. They reported high vertical GRF and peak positive free moment in LBP patients with excessive foot pronation during shod walking. To our knowledge, lower limbs' muscles activity during walking in LBP patients with excessive feet pronation has not yet to be reported. There is lack of information regarding the effects of foot pronation on various kinetic parameters and muscle activities during walking in LBP patients.

The objectives of this study were to investigate the effects of excessive feet pronation on the lower limb joint kinematics, joint moments and joint powers as well as the electromyographical activity of nine muscles at the trunk and lower limbs in able-bodied subjects with normal and PF and in PF + LBP patients during shod walking. It was hypothesized that a) the kinematics, kinetics and muscle activity during gait will be altered in individuals with PF; and b) these alterations are greater in individuals with PF + LBP.

2. Methods

2.1. Participants

In this experiment, 15 able-bodied males (age: 26.0 ± 2.9 years; height: 174.5 ± 5.5 cm; mass: 78.7 ± 9.9 kg; body mass index: 25.9 ± 3.2 kg/m^2) formed the control group and 15 other able-bodied males with PF but without LBP (PF) were part of the first experimental group (age: 25.3 ± 2.7 years; height: 173.8 ± 4.9 cm; mass: 79.4 ± 10.0 kg; body mass index: 26.3 ± 3.0 kg/m^2). The second experimental group consisted of 15 individuals with PF and LBP (PF + LBP) (age: 25.3 ± 2.9 years; height: 172.8 ± 4.4 cm; mass: 79.9 ± 3.0 kg; body mass index: 26.8 ± 1.5 kg/m^2). LBP patients were recruited from a local clinic. All subjects were right footed and right handed as determined by kicking and throwing the ball.

An orthopedic surgeon in a local clinic assessed all subjects prior to selection. A subject was included in the control group if he had no apparent musculoskeletal, postural or neurological ailment. For any of the experimental groups, subjects required a navicular drop of more than 10 mm, and a foot posture index of greater than 10 (Redmond et al., 2006). Navicular drop was measured as the difference in navicular height between non-weight bearing and full weight bearing conditions of the foot in standing position (Cote et al., 2005). Additional inclusion criteria for PF + LBP group were a LBP index of > 30 based on visual analog pain scale, and a disability index of > 10 based on Roland-Morris disability questionnaire (Mousavi et al., 2006). The between group differences on age, height, mass, and body mass index were not significant ($p > .05$). The difference between the navicular drop of PF (12.6 ± 1.7 mm) and PF + LBP (13.3 ± 1.7 mm) groups was also not significant ($p = .308$).

For all groups, the exclusion criteria were a history of major musculoskeletal surgery at trunk and/or lower limbs, neuromuscular disorders, orthopedic related diseases (except feet pronation for experimental groups, and LBP for PF + LBP), limb length discrepancies of greater than 5 mm, and if heavy physical tasks or exercises leading to fatigue were performed in the previous two days prior to the experimentation. The research protocol was approved by the ethical committee of Medical Sciences University of Hamedan (p/16/35/9/5826 – 09/02/2014). All subjects gave their informed consent to participate in the study.

2.2. Apparatus

A portable EMG system (BTS FREE EMG 300, BTS Bioengineering, Italy) with nine pairs of bipolar pre-gelled Ag/AgCl surface electrodes (circular in shape with 11 mm in diameter; 25 mm center-to-center distance; input impedance of 100 MΩ; and common mode rejection ratio of > 110 dB at 50–60 Hz) was used to record the activity of the tibialis anterior (TA), gastrocnemious medialis (Gas-M), long head of biceps femoris (BF), vastus lateralis (VL), gluteus medius (Glut-M), erector spinae at 3rd lumbar vertebral level (ES$_{L3}$), rectus abdominus (RA), external oblique (EO), and internal oblique (IO) muscles of the right side at a sampling frequency of 2000 Hz.

Skin surface over the selected muscles was shaved, cleaned with alcohol (70% Ethanol–C_2H_5OH) and abraded gently, according to the SENIAM recommendations prior to the electrodes placement (Hermens et al., 2000).

The electrodes' location for TA, Gas-M, BF, VL, and Glut-M muscles was determined based on the recommendation by SENIAM (Hermens et al., 2000). For ES$_{L3}$ muscle electrodes were placed vertically on the skin, 3 cm lateral to the related spinous process (Cheung et al., 2005; de Sèze and Cazalets, 2008; Hermens et al., 2000). For the RA muscle, electrodes were placed 3 cm from the midline of the abdomen and 2 cm above the umbilicus (Mirka and Marras, 1993). For EO muscle, the electrodes were placed 10 cm lateral from the midline of the abdomen and 4 cm above the ilium at a line oriented toward axillary an angle of 45° upward (Mirka and Marras, 1993). The electrodes for IO muscle were placed 2 cm inward and distal to the anterior superior iliac spine oriented toward umbilicus at an angle of 45°.

A Vicon MX motion analysis system including four T-series cameras (100 Hz) was used to quantify gait kinematics. Also, a Kistler force plate (Kistler AG, Winterthur, Switzerland) was used to record the GRF components at 1000 Hz. The force plate was located at the center of the calibrated walking space. EMG, motion analysis, and force plate systems were all synchronized and monitored with Nexus-1.7.5 software. Plug-in-gait model marker set (Kadaba et al., 1990) was used to define the lower limb segments.

2.3. Task, procedure, and data processing

All participants wore the same shoe model with appropriate foot size. Firstly, subject had five minutes of warm up exercises including walking. The starting point was set appropriately so that the subject had at least eight steps before entering the calibrated space and stepped on the force plate with his right foot. Three successful trials were analyzed. A trial was considered successful if the foot was landed in the middle of the force plate, all markers were visible, and the EMG signals of all muscles were recorded correctly.

EMG signals were processed as described in Farahpour et al. (2015). For EMG analysis, the peak root mean square (RMS) values of the three trials were averaged and then normalized based on the peak RMS obtained by the maximum voluntary isometric contraction (MVIC) for TA, Gast-M, BF, and VL muscles, and the submaximal isometric voluntary