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A systems-level perspective of the biomechanics of the trunk flexion-extension movement: Part I – Normal low back condition

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A B S T R A C T

Most of the previous studies of the lumbar region have not considered the influence of pelvic and lower extremity characteristics on the performance of the lumbar region. The goal of the current study was to explore these more systems-level effects by assessing the effects of a pelvic/lower extremity constraint on the biomechanical response of the lumbar spine in an *in-vivo* experiment. Twelve participants performed full range of motion, sagittal-plane trunk flexion-extension movements under two conditions: unconstrained stoop movement and pelvic/lower extremity constrained stoop movement (six repetitions in each condition over three days). Kinematics and muscle activities of the trunk and lower extremity muscles were monitored. Results showed a significant effect of pelvic/lower-extremity constraint on a number of lumbar performance measures. Trunk flexion angle was, as expected, significantly reduced with the lower extremity constraints (81° (free stoop) vs. 56° (lower extremity constrained)). At a more local level, there was a 6.4% greater peak lumbar flexion angle and a 9.1% increase in the lumbar angle at which the trunk extensor musculature demonstrated flexion-relaxation in the constrained stooping condition as compared to the unconstrained stooping condition. Also, the EMG of the L3/L4 paraspinals was greater in the restricted stooping as compared to the free stooping (16.3% MVC vs. 15.1% MVC).

Relevance to industry: Low back injuries are a significant challenge to many industries and developing accurate models of spinal stress at full stooping postures can help in the development of appropriate interventions to reduce prevalence.

1. Introduction

Standard anatomic classifications of body regions can be misleading regarding the functional biomechanical interactions between adjacent regions of the body. The existing spine biomechanics literature, for example, has provided an excellent understanding of the function of the spine as an independent unit, but a more systems-level characterization (e.g. consideration given to lower extremity influences) may provide deeper insights into its function in more realistic whole body activities. In many models and experimental studies the pelvis is regarded as a rigid, stable body on which the lumbar spine functions (e.g. Bergmark, 1989; Cholewicki and McGill, 1996, Granata and Rogers, 2007; Mirka and Marras, 1993). It is widely recognized that in real world lifting scenarios, the pelvis is not rigid or fixed but is influenced by the lower extremities and therefore documenting and quantifying these effects are important next steps in both modeling and experimental studies.

The potential influence of lower extremity structures (bones, muscles, passive tissues) on lumbar mechanics is considerable. A number of lumbar and lower extremity muscles are indirectly connected through their common insertions in the pelvis. As activation levels increase, the resulting motion of the pelvis can impact the length–tension relationship of other muscles in other regions. Many lumbar muscles originate on the ilium or sacrum (iliocostalis lumborum, quadratus lumborum, multifidus) and a number of lower extremity muscles originate on various locations on the ilium and ischium (gluteus maximus, biceps femoris, semitendinosus and semimembranosus). These posterior compartment thigh muscles span both the hip and the knee and are known to influence lumbar–pelvis interaction (i.e., lumbopelvic rhythm) and pelvis–femur interaction (i.e., pelvifemoral rhythm) (Sihvonen, 1997). The activation of the lower extremity muscles, therefore, can influence pelvic posture and thereby impact length of the low back muscles –

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affecting both their active tension capability as well as their passive tension. These effects have implications for spine loading and spinal stability.

Other studies have demonstrated these inter-region biomechanical effects through interactions of active and passive tissues. Several studies have revealed that the sacrotuberous ligaments can stabilize the sacroiliac (SI) joint during nutation of the sacrum via the activation of the biceps femoris and gluteus maximus muscles (Vleeming et al., 1989a; Vleeming et al., 1989b; van Wingerden, et al., 1993). In contrast, the sacroiliac ligaments can stabilize the SI joint during counter-nutation of the sacrum via activation of the erector spinae muscles, and the tension of the ligament decreases during activation of the gluteus maximus and traction of lumbodorsal fascia (Vleeming et al., 1996). The results suggest that there is a complementary interaction between trunk and lower extremity to achieve the stable foundation of the sacrum-ilium system. Recently, van Wingerden et al. (2004) demonstrated that SI joint stability increases with even slight activation of the erector spinae, the gluteus maximus and the biceps femoris muscles. In addition, Vleeming et al. (1995) showed the functional role of the lumbodorsal fascia in load transfer between spine, pelvis, and lower extremity by dissection in ten embalmed human cadavers and traction to various muscles such as gluteus maximus, external oblique, latissimus dorsi and biceps femoris. Through the lumbodorsal fascia these muscles may play an important role in stabilization of the trunk motion system during trunk flexion, trunk extension and trunk rotation. Pool-Goudzwaard et al. (1998) demonstrated through a biomechanical model that the lumbodorsal fascia can transmit force from the lower extremity to the trunk. In summary, this fascia creates a strong link between the trunk (i.e., spinal column) and lower extremity (i.e., pelvis) by bracing the lumbar spine and SI joints, and enhances the trunk-system level stability achieved by both pelvic stabilization and spinal stabilization.

The goal of the current study was to investigate the biomechanical interactions between the lumbar region of the spine and the pelvis/lower extremities during full range of motion, sagittal plane trunk flexion-extension movements. These are explored by documenting the impact of pelvic/lower extremity constraints on lumbar and lower extremity muscle activation profiles and lumbar and trunk kinematics. It is hypothesized that constraining the thighs and pelvis will significantly affect lumbar kinematics and muscle activations through changes in the passive tissue contributions to stability and total trunk extension moment.

2. Methods

2.1. Participants

Twelve male participants were recruited from the Iowa State University with average age 28.3 (SD 4.7) years, height 175.9 (SD 2.7) cm, and weight 73.5 (SD 6.6) kg. Participants were screened by questionnaire for chronic problems or current pain in the low back or lower extremities before experiment. Each participant provided written informed consent prior to participation, using a form approved by the institutional review board (IRB) at Iowa State University.

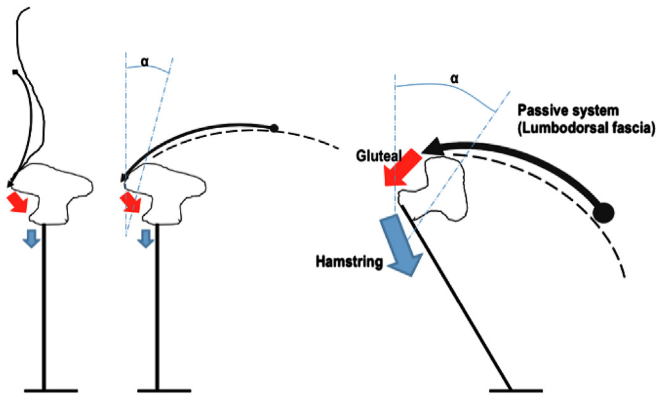
2.2. Apparatus

A lumbar dynamometer (Marras and Mirka, 1989) was used to provide the static resistance necessary to perform maximum voluntary contractions (MVCs) (both trunk flexion and extension). Surface electromyography was used to capture the activities of the twelve sampled muscles including right and left pairs of: L4 paraspinals (2 cm lateral from L4 spinous process), L3 paraspinals (4 cm lateral from L3 spinous process), rectus abdominis, external oblique, gluteus maximus and biceps femoris (Model DE-2.1, Bagnoli™, Delsys, Boston, MA) (data collected at 1024 Hz). A magnetic field-based motion analysis system was used to capture the instantaneous trunk motions (Ascension Technology Corporation, Shelburne, VT; The MotionMonitor™, Innovative Sports Training, Chicago, IL) (data collected at 102.4 Hz). Four magnetic motion sensors were placed over the S1, T12, C7 vertebrae as well as one over the xiphoid process. The pitch angle of each of these sensors captured the angle in the sagittal plane. An electrical metronome was used to maintain a constant pace for trunk flexion and extension.

The platform on which the participants stood during the experimental trials could be set up for the two different experimental conditions. In the free stooping condition the participants were free standing on the platform during the trunk flexion-extension motions – knees were locked straight, but there were not any external restrictions on the pelvis or the thighs. In the restricted stooped condition the participants' legs and pelvis were secured to a stable structure (the same vertical structure that was used to secure the pelvis during the MVC exertions) thereby maintaining verticality of the lower extremity (Fig. 1). The straps used to secure the thighs were cinched tightly across the mid-thigh level. The strap at the waist level was likewise cinched tightly, but was not a “clamp” that eliminated any pelvic rotation (Fig. 2).

2.3. Experimental design

There was one independent variable, POSTURE, with two levels: free stooping and restricted stooping. There were six kinematic dependent variables in this study: 1) peak hip flexion angle (pitch angle from the S1 sensor), 2) peak trunk flexion angle (pitch angle from the xipoid process sensor), 3) peak lumbar flexion angle (difference between the pitch angles from the T12 and S1 sensors), 4) peak lumbothoracic flexion angle (difference between the pitch angles from the xiphoid process and S1 sensors), 5) the EMG-Off lumbar angle for the L3 paraspinals, and 6) the EMG-Off lumbar angle for the L4 paraspinals. The peak values listed above simply refer to the maximum of that measure seen during a given trial. The EMG-Off lumbar flexion angles are the lumbar flexion angles at which the muscle activity level was indistinguishable from that seen in the full trunk flexion posture (i.e., point of the beginning of flexion-relaxation response). This EMG-Off angle was identified as the first point during the trunk flexion motion at which the



(a) Standing (b) Pelvic restricted stooping (c) Free stooping

Fig. 1. Representation of the difference in postures assumed during the restricted and free stooping conditions.