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Factors to consider in identifying critical points in lumbar spine flexion relaxation

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Flexion relaxation (FR), a myoelectric silence of extensor muscles near end range of lumbar flexion, is commonly reported as the lumbar flexion angle at the instant the extensor muscles become silent. However, lumbar flexion angle alone is insufficient to characterize mechanisms that modulate FR. As FR requires the moment generated by passive lumbar extensor tissues to equilibrate the moment due to gravity, the inter-relationships between lumbar moment, flexion angle, and myoelectrical silence will provide added information in the understanding of FR. The purpose of this study was to examine the relationship between lumbar moment and flexion angle throughout various flexion manoeuvres. It was hypothesized that lumbar moment and flexion angle would not be linearly related and would be affected by lower limb position, range of motion, and the addition of mass to the torso. Eleven participants performed four different lumbar flexion trials. Results showed that lumbar flexion was correlated with the lumbar moment ($r = 0.92$); however an analysis of residuals found that these measures were not linearly related. The moment was, however, correlated ($r = 0.99$) and linearly related to the sine of trunk inclination (T12 rigid body with respect to global horizontal). Future studies of FR could use trunk inclination as a simple kinematic measure to predict relative changes in lumbar moment with flexion.

1. Introduction

Flexion relaxation (FR) is a well-characterized phenomenon of the healthy lumbar spine that occurs during forward flexion. Allen (1948) and Floyd and Silver (1951, 1955) provided the first evidence that the erector spinae musculature become myoelectrically silent prior to full flexion of the spine. It is hypothesized that this phenomenon is caused by load sharing between the active extensor muscles and the passive structures of the spine (Floyd and Silver, 1955; McGill and Kippers, 1994; Toussaint et al., 1995). During flexion, passive tissues become stretched and begin to contribute an extensor moment about the lumbar spine. When the extensor moment generated by passive tissues is equal to the moment due to gravity, the extensor muscles can be turned 'off'; this instant is defined as the critical point of FR (Floyd and Silver, 1955; Morin and Portnoy, 1956). As FR is less likely to occur in individuals suffering from low back pain (Golding, 1952; Ahern et al., 1988; Kaigle et al., 1998; Mannion et al., 2001), this critical point is a potential measure for characterizing various low back disorders and their rehabilitation. In order to best use this critical point for these purposes, further research is needed to understand the factors that modulate FR and the critical point.

Lumbar spine flexion increases the moment generated within passive lumbar extensor tissues (Dolan et al., 1994; McGill and Kippers, 1994). For this reason, the critical point is often reported as the lumbar flexion angle at the instant the extensor muscles turn 'off'. This angle may be expressed as either the absolute flexion angle (Mathieu and Fortin, 2000; Gupta, 2001; Shin and Mirka, 2007; Hu et al., 2013) or the flexion angle normalized to maximum (Kippers and Parker, 1984; Sarti et al., 2001; Schinkel-Ivy et al., 2014). However, reporting the critical point as solely a function of lumbar flexion angle disregards how the moment due to gravity changes with flexion (Olsen et al., 2006). The moment due to gravity of the head, arms, and trunk (HAT) segment acting at the L4/L5 joint is dependent on the horizontal distance between the centre of mass (COM_{HAT}) and the L4/L5 joint centre. A simple model of the trunk would predict that this horizontal distance would not be linearly related to the lumbar flexion angle, but rather the sine of the trunk inclination angle with respect to horizontal (Fig. 1). Moments reported in FR studies calculated through inverse dynamics support this model, as maximum moments do not coincide with maximum lumbar flexion angles (Schultz et al., 1985; Toussaint et al., 1995; Howarth and Mastragostino, 2013).

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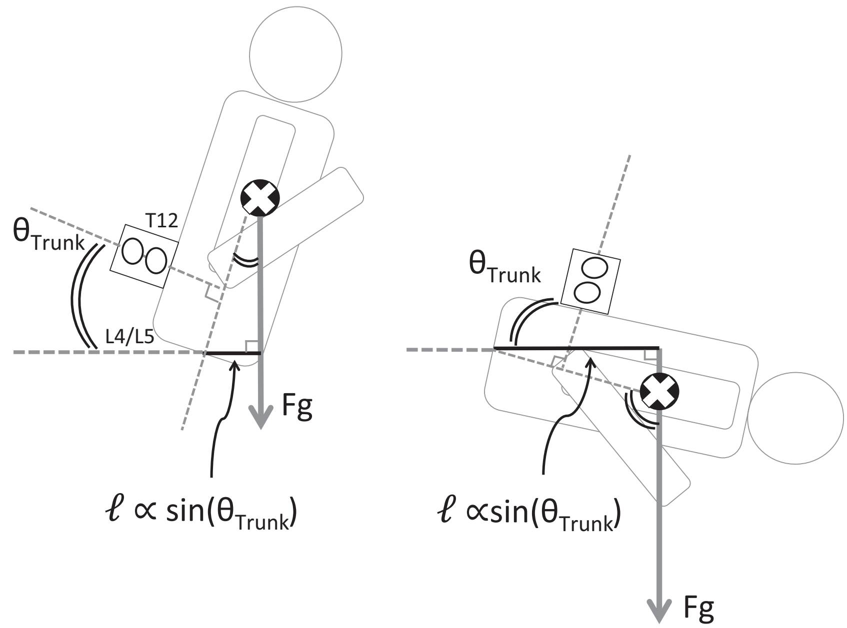

Fig. 1. Schematic of HAT segment during forward flexion. Trunk inclination (θ_{Trunk}) is the angle between the T12 rigid body and horizontal. The average trunk inclination from the quiet stance trial is subtracted from all trials so that during quiet standing $\theta_{Trunk} = 0°$. The moment due to gravity is the product of the HAT segment weight (Fg) and moment arm (ℓ). If the HAT segment is a rigid body, the moment due to gravity is expected to be proportional to the sine of θ_{Trunk}. This moment is ~0 N m in quiet stance and maximal at 90° of flexion.

The current active and passive load-sharing model of FR predicts that the critical point would be dependent on both the moment generated by passive tissues and the moment due to gravity. Solomonow et al. (2003) and Olsen et al. (2004) have thus reported the FR critical point with respect to two variables: lumbar flexion between T12 and S1 and trunk inclination between T12 and the global coordinate system. Olsen et al. (2006) improved upon this method when investigating the effect of gravity on FR by estimating the gravitational load from the trunk inclination angle. The trunk model (Fig. 1) predicts that the change in moment arm between the COM_{HAT} and L4/L5 joint centre, and therefore the gravitational load on the spine, could be estimated by the trunk inclination angle; however, this has not been validated in the literature. Cervical, thoracic, or upper limb rotations may decrease the correlation between trunk inclination and lumbar moment by altering the location of COM_{HAT}.

The primary purpose of this study was to investigate the relationship between the lumbar flexion angle and the moment due to gravity. A secondary purpose was to determine if the sine of trunk inclination could accurately predict changes in lumbar spine moment. It was hypothesized that the L4/L5 moment and lumbar flexion angle would not be linearly related, as only the moment would be affected by lower limb positions, ranges of motion, and the addition or mass to the torso. Further, a linear relationship was expected between the L4/L5 moment and the sine of trunk inclination.

2. Methods

2.1. Participant characteristics

Twelve healthy young adult males with no previous history of low back pain were recruited from the university population. During analysis one participant had to be excluded due to marker occlusion, resulting in a final total of 11 participants (mean ± SD; age 25 ± 2.5 years, height 181 ± 5.5 cm, mass 83 ± 10.6 kg). The Research Ethics Board at the university approved this study.

2.2. Protocol

As this study aimed to determine the relationship between the lumbar moment and trunk kinematics, a bottom-up inverse dynamic linked segment analysis was chosen so that trunk kinematics were not needed to perform moment calculations. Two-dimensional kinematic data were recorded (32 Hz) from the trunk, pelvis, and right leg (Optotrak 3-D investigator, NDI, Waterloo ON). Rigid bodies containing two markers each were securely adhered over the T12 and S1 spinous processes; single markers were placed over the greater trochanter, lateral knee, lateral malleolus, and distal head of fifth metatarsal; anterior and posterior superior iliac spines and iliac crest were digitized with respect to the rigid body adhered over S1. Participants were asked to stand comfortably on a force plate (AMTI Inc., Watertown MA) while ground reaction forces and moments were recorded at 2048 Hz.

A five-second quiet stance trial was collected with participants' arms held across their chest. Participants then completed trials of four different spine flexion conditions: unrestricted, restricted, sway, and weighted. For all conditions participants were instructed to slowly flex forward through their spine with arms held across their chest for three seconds and then return to neutral stance at the same pace; head position was not controlled. During the unrestricted condition, participants were instructed to flex forward as far as they could; emphasis was placed on maximizing flexion of the lumbar spine and no limitations were placed on hip movement. During the restricted condition participants were asked to flex forward as far as they could without allowing their pelvis to move posteriorly, thereby minimizing ankle, knee, and hip movement. An experimenter held a board behind the participants' ischial tuberosities to provide tactile feedback without applying a load to the participant. The sway condition had participants flex forward as far as possible. Prior to returning to upright stance, participants were instructed to slowly shift their body mass backward