Three-dimensional kinematics of the lumbar spine during treadmill walking at different speeds

Abstract The lumbar spine is of primary importance in gait and its development is influenced by the upright posture adopted in human locomotion. However, little is known about the kinematic behavior of the lumbar spine during walking. The aim of this study was to examine (1) lumbar spine kinematics during walking, (2) the effect of walking velocity on lumbar motion patterns and (3) the coupling characteristics of rotation and bending. In 22 volunteers aged 15–57 years, the three-dimensional displacements of T12 to the sacrum were sampled during elementary movements of the trunk and during walking on a treadmill at four walking velocities. A three-dimensional electrogoniometer (CA 6000 Spine Motion Analyzer) sampling at 100 Hz was used. We analyzed maximal primary and coupled motion ranges (ROM) and velocities in each plane. Lumbar ROM during walking did not exceed 40% of maximal active ROM. Transverse plane ROM and frontal and transverse velocities increased with walking velocity. Coupling of rotation and bending during walking was individually variable and dependent on walking velocity. Moreover, the smoothness of the bending-rotation path varied with walking velocity. A simplified envelope of lumbar coupling characteristics during walking is presented, and the existence of an individually variable walking speed that is characterized by a more harmonic lumbar contribution is hypothesized.

Key words Lumbar spine · Kinematics · Gait · Three-dimensional · Electrogoniometry · CA 6000

Introduction

Walking is for humans one of the most natural activities. However, although it is well known that the lumbar spine is of primary importance in gait [11] and that its development is influenced by the upright posture adopted in human locomotion [21], little is known about the kinematic behavior of the lumbar spine during this daily activity.

Several biomechanical aspects of the lumbar spine during walking have been studied previously. For instance, the resultant forces on lumbar discs and facet joints during walking have been shown to reach 2.5 times the body weight [4], although lower and higher peak loads have been described [7, 9, 13, 14]. A recent in vivo study by Wilke et al. [32], for example, showed much lower intradiscal pressures during gait, which were only moderately larger than those registered during relaxed standing or sitting. It is, however, not known whether these pressures are altered in patients with low back disorders. Lumbar loads during gait have been shown to increase with increasing walking velocity [7], although this finding remains controversial [32]. Peak erector spinae contraction forces during walking (140 N) are larger than those of the remaining trunk muscles (about 15 N) [9]. A study by Vink and Karssmeijer [28] showed bilateral activity of
intrinsic lumbar back muscles during double support. After heel strike, the homolateral muscles displayed a larger activity. This study revealed no clear relationships between pelvic sagittal and frontal rotations and muscle activation. The bilateral activity of the erector spinae was shown to occur at two points in the cycle [5]. Its total duration was 15–26% of the stride cycle. Thorstensson et al. [25] demonstrated that sagittal and frontal movements of the trunk have different paths and vary with walking velocity. The bilateral co-contraction of multifidus and longissimus just before heel strike is posited to have the effect of restricting trunk movements in the frontal plane during gait.

Clinical applications in patients suffering from low back pain showed an increase of lumbar muscle activity during the swing phase [1].

Vogt et al. [29] analyzed the kinematics and electromyographic (EMG) activation patterns of several muscles during walking. This study showed, during slope walking (10%), a significant increase in lumbar frontal and transverse motion ranges during walking as compared to level walking. Syczewska et al. [24] showed that sagittal angular changes of various spine segments during walking displayed quite similar patterns in healthy volunteers, whereas frontal plane angular changes varied from segment to segment. In the lumbar spine, bending occurred towards the swinging leg. Whittle and Levine [31] obtained average lumbar motion ranges during gait at free velocity of 4.0°, 7.6° and 8.3° in the sagittal, frontal and transverse plane respectively. Lumbar lordosis displayed large individual variations [30,31]. Lumbar lateral bending occurred towards the supporting leg; its range was equal to the pelvic tilt. Lumbar axial rotation was slightly less than pelvic rotation, and a phase lag was observed between pelvic and lumbar rotation.

The aims of the present study were to determine the three-dimensional patterns of lumbar kinematics during gait and the influence of increasing walking velocity on these parameters. In particular, the coupling between axial rotation and lateral bending was analyzed. Although still a matter of controversy, coupling of bending and rotation during elementary trunk motion has been studied by several authors [3, 8, 16, 17, 18,22]. However, little is known about this aspect during gait, despite the fact that such information might be useful in fundamental and clinical conditions for several disorders or deformities, such as idiopathic scoliosis and chronic low back pain. Three-dimensional motion of T12 to the sacrum was sampled using a three-dimensional electrogoniometer in 22 subjects walking on a treadmill at different walking speeds (Fig. 1).

Materials and methods

Twenty-two asymptomatic volunteers participated in this study. Their mean age was 34 years (range: 15–57 years). Nine were female and 13 male.

The height, weight, trunk height (measured in seated position), and length of the lower extremities (anterior superior iliac spine to medial malleolus distance) were registered for each subject. Three-dimensional motion between the sacrum and T12 was tracked using a six-degree-of-freedom instrumented spatial linkage (CA 6000 Spine Motion Analyzer, OSI, USA). The reliability and reproducibility of this instrument was validated in a previous study [10]. The linkage was mounted on the subject using a pelvic and a thoracic harness (Fig. 1). The sampling rate was set to 100 Hz. Global lumbar spine motion was sampled during elementary trunk movements (flexion-extension, lateral bending and axial rotation). These were carried out actively at a free pace in standing position. From neutral position, the subject was instructed to first reach maximal flexion or right bending or rotation and then continuously move to the maximal opposite motion before regaining the original neutral position. Each of these movements was repeated four times. Lumbar kinematics was then sampled during walking on a motorized treadmill (Tunturi 502 Electronic Jogging Machine, Tunturi, Finland) at four walking velocities (0.8, 1.1, 1.4 and 1.7 m/s). The subject was allowed to practice on the treadmill for 5–10 min. Eight to 12 gait cycles were sampled at each walking velocity.

The parameters considered were

1. Average motion ranges (ROM) in each plane (averaged over all cycles)
2. Coupling of lateral bending and rotation
3. Peak motion velocities in each plane

The statistical analysis aimed at evaluating

1. The effect of increasing walking velocity on lumbar kinematics
2. The relation of lumbar kinematics during gait to kinematics during elementary movements and to anthropometric parameters