Pathophysiology 12 (2005) 295–302

ISP PATHOPHYSIOLOGY

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Lumbar spine intersegmental motion analysis during lifting

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Received 24 February 2005; received in revised form 8 September 2005; accepted 9 September 2005

Abstract

There are a lot of in vitro and also in vivo studies under strictly restricted and subject-demanding laboratory conditions using X-ray or MRI recordings, but very few studies give information about the lumbar spine intersegmental behavior in daily life activities. Aims of this study were to measure the intersegmental lumbar spine motions during lifting trials and to determine the different motion patterns of different subjects performing comparable lifting tasks. First, 11 healthy volunteers had to perform lifting tasks (box weight 4–15 kg) using their favorite lifting technique (no instructions by the researcher). The coordinates of skin-markers attached on lumbar spines of the subjects were measured using 3D-motion capturing and then transformed to Cardan-angles. Second, 23 volunteers performed lifting tasks (box weight 4–15 kg) with the instruction to bend their knees during lifting. Coordinates of this smaller set of markers on lumbar spines of the subjects were transformed to intersegmental angles using a spline-method. From the first experiment three groups of motion patterns are distinguishable: subjects who used only small intersegmental range of motion within their upper lumbar spine and bended their knees during lifting were in contrast to subjects who used 3.25 times wider range of motion in the upper lumbar spine and did not bend the knees (cluster analysis, $c = 0.76$). The third group was not assignable to these other two groups. Within all lifting trials of the second experiment different groups were detectable also: in spite of all subjects bended their knees, there were subjects with wide range of motion of lumbar spine motion segments. Other subjects were able to reduce intersegmental range of motion (k-means clustering, msv > 0.47). From this it follows that the intersegmental motion of lumbar spine is individually different and not equal for all lumbar levels. Furthermore, lifting technique influenced the motion of the lumbar spine. But not for all subjects, the advice to bend the knees during the lifting effectively reduced the lumbar motion ranges. In conclusion: special instructions to reduce lumbar spinal motion are recommended. Due to different lumbar spine motion patterns, different loading situations are anticipated because of changing lever arms and angular accelerations. This understanding is important in reducing spinal loading and to prevent spinal disorders in manual material handling tasks.
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Keywords: Lumbar spine; Three-dimensional recording; Intersegmental motion; Lifting

1. Introduction

The understanding of the positions of lumbar vertebrae is necessary when the spinal spatial configuration, posture, motion and loading are estimated. With increasing costs of low back pain and spinal disorders [1] spinal loading during daily life activities is on the focus of present ergonomic research. Most of spinal motion or loading studies in real life situations investigate, however, the global angles between the thorax and pelvis [2–4]. It seems that intersegmental lumbar motions have been well investigated. There are several in vitro studies where the functional spinal units have been investigated by measuring accurately the range of motion and the centers of rotation, the torques and forces in specimens while bending and compressing them. Furthermore shear-forces or torques have been studied in conditions where the vertebral bodies or intervertebral discs get injured [5–12]. The main problem of these data is the extrapolation to daily life situations because of the different mechanical behaviors of lumbar spine motion segments in living subjects. Furthermore the role of muscles is important and that has not been clarified in these studies. Using X-ray, magnet

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0928-4680/$ – see front matter © 2005 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.pathophys.2005.09.003

resonance imaging or video fluoroscopy the intersegmental spinal motions have also been measured under restricted laboratory conditions [13–18]. These devices extensively constrict the subjects, and they cause abnormal motion behaviors. Mostly poor flexion/extension motions with fixed pelvis or in sitting posture have been investigated. Also the poor time resolution does not permit an adequate description of spinal motions. X-ray techniques and fluoroscopy also cause high radiation exposures, and in healthy subjects this is ethically problematic. The restricted methods to measure the intersegmental spinal motions are invasive studies with bone pins stacked through the skin, the muscles, connecting tissue to sign the positions of the vertebrae [19–21]. The pins, needles or wires stuck through muscles and ligaments influence the behavior of muscles and ligaments. Since these tissues control the motions and mechanical behavior of the underlying bony structures, the motions of vertebrae become restricted both physically and through pain. Ethical reflection is another important fact that speaks against such methods.

In daily life activities like lifting, only a few studies using skin-marker methods have looked at the whole lumbar spine and its manifold possibilities of motion at different levels. There are findings that high external loads lead to large intersegmental ranges of motion. Older people show smaller range of motion than younger [22]. While lifting, the trunk has to be tilted in sagittal plane, and it has been shown that the change of angle of lordosis as an interaction of all lumbar motion segments depends on the trunk-tilt-angle: the more the trunk is tilted, the more the lordosis-angle is reduced. Some subjects actually show negative angles, which means that the lordosis is nullified and the lumbar spine is in temporary kyphotic posture during lifting [23]. On the other hand it has been reported that the speed of motion and the load have no influence of lumbar performance. Only the time to accelerate motion segments was shortened performing fast lifting trials [24].

The main problem of skin-surface-marker methods is the relative motion of soft tissues lying over the bony structures. In the estimation of the skin-marker coordinates applied on lumbar spines and coordinates of assigned landmarks on the vertebrae of nine subjects using open MRI a linear relation has been found in five observed postures. Comparable coherence was verifiable for translation-vectors and spatial orientation of skin-markers and associated landmarks on lumbar vertebrae ($r > 0.68$). Further skin motion seems to have only small influence on the measurements on the surface and may be neglected. [25] Comparable results have been reported by Bryant et al. [26] and Labesse et al. [27]. Especially skin-markers over the spinous processes provide good possibility to estimate lumbar vertebral position and motion.

Aims of this present study were to measure the parameters of intersegmental lumbar motion during lifting. The motion range of single lumbar segments, L1–2, L2–3 down to L5–pelvis were clarified. Data of maximum movement-amplitudes of different subjects or subject groups were compared and assessed. Furthermore time-dependent motion patterns of lumbar spine motion segments of different lifting techniques are presented. In addition, the factors affecting the lumbar spine motion patterns were investigated (squat or stoop lifting technique and loading).

2. Methods

2.1. Experiment a: individual lifting technique

Eleven healthy volunteers with no history of low back pain (four females and seven males; mean age: 26 ± 2.6 years; weight: females, 58 ± 3.6 kg; males, 77.3 ± 5.5 kg; length: females, 172 ± 6 cm; males, 183 ± 5 m) performed lifting tasks using their likeable individual lifting technique. They had to lift boxes in front of their feet from the floor up to the hips, rest for about 2 s and put the box down to the floor. No further instruction, how to lift was given by the researchers. Box weight was randomly changed from 4 up to 15 kg. Each box weight was lifted five times so that the subjects had to perform 15 lifting tasks. All subjects following the requirements of the local ethical commission gave written consent. The study was approved by the local ethics committee (0558-11/00) and, therefore, fulfils the declaration of Helsinki.

Infrared-light reflecting markers ($n = 19$) were applied to the lumbar backs of the subjects to estimate the intersegmental lumbar motions. For this, spinous processes were palpated in sitting posture so each lumbar spinous process could be signed by one marker. Five markers flag muscle bellies of m.erector spinae left and right side of the spinous processes approximate 3 cm beside and above the spinous-process-markers. The last four markers signed the pelvis, two markers were applied to left and right spina iliaca posterior superior, and two markers left and right side of crista iliaca.

Coordinates of described markers were measured during the lifting trials using three-dimensional motion capturing at a sampling rate of 100 Hz and with the dynamic spatial resolution of 0.33 mm (Qualisys, Gothenburg, Sweden).

Raw coordinates were filtered (3rd-order Savitzky-Golay-filter using 70 samples), gaps were filled via cubic interpolation. Processed data were transformed to intersegmental Cardan-angles (α: flexion, β: lateral bending, γ: axial torsion) for the motion segments L1–2, L2–3, L3–4, L4–5 and L5–pelvis, respectively, using a standard global Cartesian system of coordinates (x-axis right–left, y-axis anterior–posterior, z-axis caudal–cranial in relation to the subject). The maximum change of intersegmental Cardan-angles while put-down-phase was calculated, proofed by cluster analysis and presented for the discriminated subgroups. Further time-dependent angular behavior of lumbar motion segments were resampled to standard length oriented on stoop-lifting-cycle. Motion of single lumbar motion segments during stoop-lifting-cycle in relation to the flexion-angle of L5–pelvis were presented for

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