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Original article

Effects of slouching and muscle contraction on the strain of the iliolumbar ligament

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Abstract

The study consisted of biomechanical modelling and in vitro experiments. The objective of the study was to find a mechanical cause of acute low back pain (LBP) in everyday situations. The precise mechanism producing LBP is still under discussion. Most biomechanical studies link the concepts of stooped postures and buckling instability of the spine under high compressive load. No biomechanical model addresses situations with small or neglectable compressive spinal load. The proposed conceptual model describes strain on the iliolumbar ligaments (ILs) when slouching from standing upright. Delayed or absent recruitment of back muscles that protect against hyperkyphosis of the lumbar spine is a conditional factor. Erector spinae and multifidus muscle forces are included, representing a bifurcation in back muscle force: one part acting on the iliac bones and one part acting on the sacrum. The multifidus muscle action on the sacrum may produce nutation which can be counteracted by pelvic floor muscles, which would link back problems and pelvic floor problems. The effect of simulated muscle tension on the ILs and the L5-S1 intervertebral disc angle was measured using embalmed specimens. Forces were applied to simulate erector spinae and sacral part of multifidus tension, bilateral up to 100 N each. Strain gauge sensors registered elongation of the ILs. Explorative biomechanical model calculations show that dynamic slouching, driven by upper body weight and (as an example) rectus abdominis muscle force may produce failure load of the spinal column and the ILs. The quasi-static test on embalmed specimens showed a significant increase of IL elongation with simulated rectus abdominis muscle force. Adding erector spinae or multifidus muscle tension eased the ILs. Sudden slouching of the upright trunk may create failure risk for the spine and ILs. This loading mode may be prevented by controlling loss of lumbar lordosis with erector spinae and multifidus muscle force.

Keywords: Low back pain; Multifidus muscle; Pelvic floor; Iliolumbar ligament

1. Introduction

The cause of low back pain (LBP) is often attributed to intolerable high intradiscal pressure. Use of the spinal compression model is often referred to for workload standards (Kumar, 1994) and is the starting point for spinal buckling instability models (Howarth et al., 2004) for lifting in stooped postures. The precise mechanism producing back sprain is, however, still under discussion. Therefore, we decided to explore a novel approach. In contrast to established biomechanical research we do not relate injury risk to forward trunk inclination, but take the unconstrained erect posture as a starting point.

In a previous study (Snijders et al., 2004) we developed a biomechanical model on sitting with hyperkyphosis while leaning against a high backrest. For verification of the model we measured in vitro stepwise backward tilt of the pelvis combined with forward flexion of the spine. We found that during forward flexion of the L5 vertebra the sacrum moved in the

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opposite direction (counternutation). During the same test we measured (indirectly) elongation of the iliolumbar ligaments (ILs). The increase of strain on the IL by forward flexion of L5 was similar to that reported earlier (Müller-Gerbl et al., 1988, Paul, 1989).

Because patients suffering from acute LBP often present with pain at the site of the IL we decided to develop a model on sudden slouching. Starting point was the absence or delay of protective muscle force. A higher incidence of LBP was found in athletes showing delayed muscle reflex response on a quick force release in trunk flexion, extension and lateral bending (Cholewicki et al., 2005). In continuation of our earlier biomechanical model on sitting we decided to model dynamic slouching of the upright trunk. The aim of the present study was to assess failure risk of the IL by means of explorative calculations (see Appendix A) and to measure in vitro if such risk could be prevented by back muscles. The following hypothesis was postulated: tension in the IL increases with forward flexion of L5 and decreases by multifidus and erector spinae muscle contraction.

2. Materials and methods

2.1. Materials

Four embalmed specimens (age range 63–86 years) consisting of L4, L5 and pelvis with intact ligaments and intervertebral discs were loaded on a specially designed apparatus (see Fig. 1).

2.2. Methods

An embalmed pelvis was placed upright with 12 degrees backward inclination of the tangent plane to the symphysis and the left and right spina iliaca anterior superior (Fig. 1). The upper part of L4 was attached to a vertical bar by means of a clamp with screws. Screws were inserted in the specimen and ropes were adjusted to simulate the rectus abdominis, the sacral part of the multifidus and the lateral part of the erector spinae muscles. The site of muscle attachments was taken as an average of 5 cadavers and measured with respect to the axis of the spine. The distances were at the L4 level 11, 5.5 and 3 cm, respectively.

The tension in the cords was increased with steps of 20 N. We used a flexion moment of 22 N m. A smaller magnitude (10 Nm) was used in earlier studies (Müller-Gerbl et al., 1988; Paul, 1989; Yamamoto et al., 1990), resulting in an average strain ($n = 6$) of 6.8% (SD 12%) in the ventral band of the IL (Paul, 1989).

Strain of the IL was measured with sensors attached to the ventral band of each IL halfway between the transverse process of L5 and the ilium.

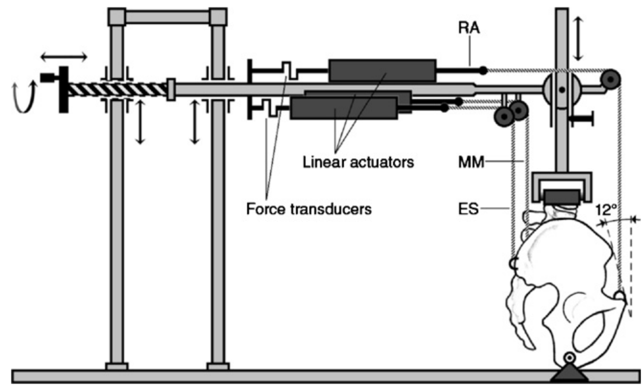

Fig. 1. Load test on embalmed specimen in the posture shown in Fig. 3B (Appendix A). The IL elongation is measured while flexing the spine. The pelvis is rotated backward by means of cords representing the rectus abdominis muscles (RA). Additional cords are tightened simulating erector spinae (ES) or multifidus (MM) muscles.

The movements of the ventral side of L5, sacrum and ilium were recorded with a 3-D videorecording system.

2.3. Instrumentation

Partial upper body weight was simulated by means of a construction (75 newton = 75 N = ca. 7.5 kg) fixed on top of L4. Pelvic inclination was adjusted with a spindle via a horizontal bar hinging with a vertical bar. Linear actuators (motor LA12-100-24-001, 0–500 N, Linak, Breda, the Netherlands) tightened cords (loading rate 2 mm/s), guided by pulleys, to simulate muscle forces with fixed lever arms of these muscles with respect to the axis of the vertical bar. Tension in the cords was measured using custom- made strain-gauged force transducers (linearity 1.2%, 0–100 N). For the assessment of change in ligament elongation both ends of a custom-made sensor (U-shape bend strip) with strain-gauges (Müller-Gerbl et al., 1988; Paul, 1989) were attached to the IL by means of pins at both ends of the strip (linearity 0.7%, 0–5%). For 3-D videorecording with 2 CCD cameras of relative movements of bones, retroreflective markers were attached to the bones; accuracy was 0.1 degree (Keemink et al., 1991).

2.4. Data analysis

The *t*-test for zero slope was applied with significance level $P < 0.05$. We were interested in the trend of measured quantities (increase or decrease), not in the absolute values.

3. Results

Simulation of rectus abdominis force in the erect position of the embalmed specimens resulted in elongation of the IL, left and right (results of the right IL of