Journal of Biomechanics 49 (2016) 890–895

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

In vivo loads on a vertebral body replacement during different lifting techniques

Marcel Dreischarf*, Antonius Rohlmann, Friedmar Graichen, Georg Bergmann, Hendrik Schmidt

Julius Wolff Institute, Charité – Universitätsmedizin Berlin, Augustenburger Platz 1, 13353 Berlin, Germany

ARTICLE INFO

Article history:
Accepted 14 September 2015

Keywords:
Lumbar spine
In vivo load measurement
Lifting
Spinal loading
Stoop and squat lifting

ABSTRACT

The repeated lifting of heavy weights has been identified as a risk factor for low back pain (LBP). Whether squat lifting leads to lower spinal loads than stoop lifting and whether lifting a weight laterally results in smaller forces than lifting the same weight in front of the body remain matters of debate.

Instrumented vertebral body replacements (VBRs) were used to measure the *in vivo* load in the lumbar spine in three patients at level L1 and in one patient at level L3. Stoop lifting and squat lifting were compared in 17 measuring sessions, in which both techniques were performed a total of 104 times. The trunk inclination and amount of knee bending were simultaneously estimated from recorded images. Compared with the aforementioned lifting tasks, the patients additionally lifted a weight laterally with one hand 26 times.

Only a small difference (4%) in the measured resultant force was observed between stoop lifting and squat lifting, although the knee-bending angle (stoop 10°, squat 45°) and trunk inclination (stoop 52°, squat 39°) differed considerably at the time points of maximal resultant forces. Lifting a weight laterally caused 14% less implant force on average than lifting the same weight in front of the body.

The current *in vivo* biomechanical study does not provide evidence that spinal loads differ substantially between stoop and squat lifting. The anterior–posterior position of the lifted weight relative to the spine appears to be crucial for spinal loading.

1. Introduction

During daily activities, the human lumbar spine is subjected to high loads while providing a high compliance to perform complex motion tasks. These multifaceted requirements appear to be closely related to the high incidence of low back pain (LBP), which is associated with high rates of disability from work and thus tremendous costs for society (Vos et al., 2012; Wenig et al., 2009). Numerous epidemiological studies on the relationship between physical loads and the occurrence of LBP note lifting, in particular the lifting of heavy weights at higher frequency, as a risk factor for LBP (Frymoyer et al., 1983; Hoogendoorn et al., 2000; Kelsey et al., 1984; Palmer et al., 2003). Therefore, a better biomechanical understanding of the spinal loading of the lumbar spine during different lifting techniques and potential influencing factors is of prime importance.

During the last decades, the spinal loading during stoop lifting (i.e., back lifting – knees straight and back bent) and squat lifting (i.e., leg lifting – knees bent and back straight) have been frequently investigated and controversially discussed (Hsiang et al., 1997; Van Dieën et al., 1999). For a detailed biomechanical understanding of these two basic techniques, a reliable, objective and valid measurement of the loading during both approaches is required. However, the complexity and invasiveness of such a measurement have resulted in only a few attempts to directly measure *in vivo* spinal loading, in particular during complex activities such as lifting. By measuring the intradiscal pressure (IDP) in the nucleus pulposus of the L3–L4 disc, Nachemson and Elfström (1970) compared both techniques in six healthy volunteers lifting two 10-kg barbells from a chair. Their results indicated that stoop lifting increased the load by a factor of ~2.3 with respect to upright standing with 10 kg in each hand, substantially more than with the squat technique. Andersson et al. (1976) measured similar but small, non-significant tendencies in four healthy volunteers (L3–L4). In a summary study on several IDP measurements, Nachemson (1981) concluded that both lifting techniques result in load differences of only approximately 10% when lifting a weight of 10 kg. However, more recent measurements in only one healthy volunteer by Wilke et al. (2001) demonstrated an approximately 35% increased pressure in L4–L5

---

* Corresponding author. Tel.: +49 30 209346143; fax: +49 30 209346001.
E-mail address: dreischarf@julius-wolff-institut.de (M. Dreischarf).

http://dx.doi.org/10.1016/j.jbiomech.2015.09.034
0021-9290/

while lifting a crate from the ground with the stoop compared with the squat lifting technique. These IDP measurements during lifting allow a unique understanding of the spinal loading. However, the results of these studies remain limited due to the small number of measured subjects who were typically only measured once during a single measurement session; thus, intra-individual variations were not assessed. Furthermore, important influencing factors, such as the amount of trunk inclination and knee bending performed, were mostly not evaluated or quantified.

To overcome these drawbacks, alternative non-invasive approaches were developed and employed to estimate spinal loading during lifting in a controlled laboratory environment. Van Dieen et al. (1994) and Rabinowitz et al. (1998) used stadiometry and quantified spinal loading by precisely measuring spinal shrinkage after performing several minutes of repeated lifting. Both groups observed non-significant differences between stoop and squat lifting. In a review study, Van Dieën et al. (1999) compared numerous published investigations in which mainly net-moments or model estimations of the spinal compression forces during both techniques were determined. These researchers concluded that the biomechanical literature does not support the utilization of squat or stoop lifting. In contrast, recent combined approaches using a hybrid dynamic kinematics-based finite element model and *in vivo* kinematics measurements by Bazrgari et al. (2007) advocated squat over stoop lifting because of predicted smaller net moments, muscle forces and spinal loads. In addition to these two basic lifting concepts, wherein the weight is placed in front of the body, lifting a weight placed laterally to the body with one hand may be required during daily activities. However, only a few studies (e.g., Davis and Marras, 2005; Faber et al., 2009; Marras and Davis, 1998) investigated the potential differences between these two main weight locations and their influence on spinal loading. Thus, due to these partially conflicting results from past investigations and the lack of literature values, direct approaches that objectively quantify loading during lifting in several individuals and measurement sessions could shed light on the ongoing discussion regarding spinal loading during different lifting techniques.

A telemeterized vertebral body replacement (VBR) enables the *in vivo* measurement of implant forces in the lumbar spine in multiple repeated measurements and can be used to investigate potential influencing factors on spinal loading in several subjects (Rohlmann et al., 2007). In the present study, patients with instrumented VBRs performed numerous lifting exercises to compare squat lifting with stoop lifting and to determine the influence of the initial weight location. We hypothesized that

1. the stoop lifting technique results in a substantially increased load while lifting a weight in front of the body from the ground compared with the squat lifting technique, and
2. lifting a weight laterally with one hand results in smaller implant forces than lifting the same weight in front of the body.

2. Methods

2.1. Telemeterized vertebral body replacement

To measure the *in vivo* loads in the lumbar spine, standard VBRs (Synex™, Synthes, Bettlach, Switzerland) were modified by inserting strain gauges, a telemetry unit, and a coil for an inductive power supply. These modifications allow measurements of all three force and three moment components acting on the implant. To intraoperatively allow adaptation of the implant to the individual defect size, screwed-on endplates of different heights were employed.

Prior to the implantation, each VBR was extensively calibrated by applying various well-defined combinations of compressive and shear forces onto the implant in a calibration chamber. The loads caused defined combinations of forces and moments, for which the measurement accuracy was better than 2% for forces and 5% for moments relative to the calibration ranges. The sensitivity of the VBR was less than 1 N for the force components and less than 0.01 N m for the moment components. A detailed description of the implant, its modifications and calibration can be found elsewhere (Rohlmann et al., 2013, 2007).

The power for the implant was supplied by an inductive coil, which was placed around the patient's trunk during the measurement. Furthermore, an antenna was attached to the patient's back, which received the load-dependent signals of the telemetry. These signals were transmitted to a computer, where the forces and moments were calculated and displayed on a monitor. During all measurement sessions, the patients were videotaped, and the digital telemetry signals and the video data were synchronously stored together.

2.2. Ethics statement

All the patients signed a written informed consent form, in which they agreed to the implantation of the instrumented VBR, implant load measurements and the publication of their images. The subjects rights were protected throughout the course of the study. The Ethics Committee of the Charité – Universitätsmedizin Berlin approved the implantation of the implant in patients and the study protocol (Registry number: 213-01/225-20).

2.3. Patients

Four male patients with telemeterized VBRs participated in the present study (WP1, WP2, WP4 and WP5). All of the patients had an A3-type compression fracture of a lumbar vertebral body (classified according to Magerl et al. (1994)). A detailed description of these patients is provided in Table 1. Three of the patients received a VBR in the first lumbar vertebra “L1” (WP1, WP2 and WP4), whereas patient WP5 received a VBR in the third lumbar vertebra “L3”. Prior to the VBR implantation, the unstable burst fracture was stabilized posteriorly using an internal spinal fixation device. In a second surgery, parts of the fractured vertebral body and the adjacent intervertebral disks were removed, and the VBR was implanted into the corpectomy defect. Autologous bone material was employed to enhance the interbody fusion process.

2.4. Exercises

During several measurement sessions at different postoperative time points, the patients were asked to lift a bottle crate in front of their body from the ground. Prior to the lifting tasks, the patients were introduced to the two basic concepts: stoop lifting and squat lifting. For squat lifting, the patients were taught to keep their backs as straight as possible and to bend their knees to lift the crate. In contrast, for stoop lifting, the patients were taught to keep their knees straight and to lift the crate by bending the upper body. Without further instructions, the patients subsequently lifted the crate 2–4 times using both techniques in the same session (Fig. 1). Overall, stoop and squat lifting were compared in four patients in 17 measuring sessions, in which both techniques were performed a total of 104 times (Table 1).

To evaluate the influence of the initial location of the weight on the implant loading, patients lifted an identical crate laterally with one hand in addition to the aforementioned lifting tasks with the weight in front of the body. For this assessment, the crate was located laterally to the feet, and patients were asked to lift the