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Short communication

# Optimised loads for the simulation of axial rotation in the lumbar spine

Marcel Dreischarf, Antonius Rohlmann*, Georg Bergmann, Thomas Zander

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

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ABSTRACT

Simplified loading modes (pure moment, compressive force) are usually applied in the *in vitro* studies to simulate flexion-extension, lateral bending and axial rotation of the spine. The load magnitudes for axial rotation vary strongly in the literature. Therefore, the results of current investigations, e.g. intervertebral rotations, are hardly comparable and may involve unrealistic values. Thus, the question 'which *in vitro* applicable loading mode is the most realistic' remains open.

A validated finite element model of the lumbar spine was employed in two sensitivity studies to estimate the ranges of results due to published load assumptions and to determine the input parameters (e.g. torsional moment), which mostly affect the spinal load and kinematics during axial rotation. In a subsequent optimisation study, the *in vitro* applicable loading mode was determined, which delivers results that fit best with available *in vivo* measurements.

The calculated results varied widely for loads used in the literature with potential high deviations from *in vivo* measured values. The intradiscal pressure is mainly affected by the magnitude of the compressive force, while the torsional moment influences mainly the intervertebral rotations and facet joint forces. The best agreement with results measured *in vivo* were found for a compressive follower force of 720 N and a pure moment of 5.5 Nm applied to the unconstrained vertebra L1.

The results reveal that in many studies the assumed loads do not realistically simulate axial rotation. The *in vitro* applicable simplified loads cannot perfectly mimic the *in vivo* situation. However, the optimised values lead to the best agreement with *in vivo measured values.* Their consequent application would lead to a better comparability of different investigations.



## 1. Introduction

In finite element analyses and *in vitro* experiments on the spine, simplified loading modes (pure moment, compressive force) are usually employed to simulate the elementary movements: flexion-extension, lateral bending and axial rotation. Realistic loading is required, e.g. for pre-clinical tests of implants. However, only for upright standing and flexion-extension, loading recommendations for a realistic simulation exist (Rohlmann et al., 2009a, 2009b) while for axial rotation, published loading modes vary strongly. Employed torsional moments and axial compression forces differ between 3.75–14.5 Nm (Gunzburg et al., 1991; Wilke et al., 2001b) and 0–1000 N (Noailly et al., 2005; Wilke et al., 1998), respectively. Furthermore there are differences in the direction of the torsional moment vector and in the boundary conditions of the most cranial vertebra, which result from different *in vitro* experimental setups. Due to these different loads and boundary conditions the results of current studies are usually incomparable and may take on unrealistic values.

The main mechanical effect of axial rotation in the lumbar spine can be described by two *in vivo* measurable parameters, intervertebral rotation (IVR) and intradiscal pressure (IDP). Wilke et al. (2001a) measured the IDP for one-sided axial rotation during standing. The IVR during the same motion was measured *in vivo* by several groups (Table 1) using invasive or non-invasive techniques. Their results revealed that segmental IVRs are about 1° in the lumbar spine.

The aims of this study were threefold: (1) to estimate the global scattering of the results of current investigations due to different loading modes, (2) to identify the loading parameters, which most strongly affect the results when axial rotation is simulated, and (3) to optimise these parameters to find an *in vitro* applicable loading mode for axial rotation, where the calculated parameters IVR and IDP agree best with averaged *in vivo* measured data.

## 2. Methods

### 2.1. Finite element model of the intact lumbar spine

A non-linear finite element model of the osteoligamentous lumbar spine was employed (Fig. 1). The nuclei pulposi were simulated as incompressible fluid filled cavities and the annuli fibrosi were modelled as fibre-reinforced hyperelastic

* Corresponding author. Tel.: +49 30 450559083; fax: +49 30 450559980.
*E-mail addresses:* antonius.rohlmann@charite.de, rohlmann@biomechanik.de (A. Rohlmann).

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