Journal of Biomechanics 44 (2011) 1478–1483

Contents lists available at ScienceDirect

Journal of Biomechanics

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

# The feasibility of modal testing for measurement of the dynamic characteristics of goat vertebral motion segments

S.J.P.M. van Engelen [a,b], A.J. van der Veen [c], A. de Boer [d], M.H.M. Ellenbroek [d], T.H. Smit [a,e,f], B.J. van Royen [a,e,f], J.H. van Dieën [a,b,]*

[a] Research Institute MOVE, VU University Amsterdam, The Netherlands
[b] Faculty of Human Movement Sciences, VU University Amsterdam, The Netherlands
[c] Department of Physics and Medical Technology, VU University Medical Centre, Amsterdam, The Netherlands
[d] Department of Applied Mechanics, University of Twente, Enschede, The Netherlands
[e] Skeletal Tissue Engineering Group Amsterdam, VU University Medical Centre, Amsterdam, The Netherlands
[f] Department of Orthopaedic Surgery, VU University Medical Centre, Amsterdam, The Netherlands

ARTICLE INFO

*Article history:*
Accepted 9 March 2011

*Keywords:*
Biomechanics
Goat
Structural vibration testing
Resonance frequency
Mode shape

ABSTRACT

Structural vibration testing might be a promising method to study the mechanical properties of spinal motion segments as an alternative to imaging and spinal manipulation techniques. Structural vibration testing is a non-destructive measurement technique that measures the response of a system to an applied vibration as a function of frequency, and allows determination of modal parameters such as resonance frequencies (ratio between stiffness and mass), vibration modes (pattern of motion) and damping. The objective of this study was to determine if structural vibration testing can reveal the resonance frequencies that correspond to the mode shapes flexion–extension, lateroflexion and axial rotation of lumbar motion segments, and to establish whether resonance frequencies can discriminate specific structural alterations of the motion segment. Therefore, a shaker was used to vibrate the upper vertebra of 16 goat lumbar motion segments, while the response was obtained from accelerometers on the transverse and spinous processes and the anterior side of the upper vertebra. Measurements were performed in three conditions: intact, after dissection of the ligaments and after puncturing the annulus fibrosus. The results showed clear resonance peaks for flexion–extension, lateral bending and axial rotation for all segments. Dissection of the ligaments did not affect the resonance frequencies, but puncturing the annulus reduced the resonance frequency of axial rotation. These results indicate that vibration testing can be utilised to assess the modal parameters of lumbar motion segments, and might eventually be used to study the mechanical properties of spinal motion segments in vivo.


## 1. Introduction

Mechanical functioning of the spine is to a large extent determined by the mechanical properties of the intervertebral disc, facet joints and ligaments. Degeneration of the disc, facet joints and ligaments can lead to alterations in the stiffness of motion segments, which might cause the spine to become unstable (Schmidt et al., 1998; Haughton et al., 1999; Mao et al., 2005; Zhao et al., 2005). The stiffness of the spine may also be altered by spinal surgery. For example, surgery targeting spinal stenosis often implicates that the overlying lamina and the supraspinous ligament of the motion segment are removed, which might destabilise the spine (Tai et al., 2008; Subramaniam et al., 2009; Van Solinge et al., 2010).

The treatment of segmental instability aims at increasing segmental stiffness. To decide whether restabilising instrumentation is needed and which segments should be targeted, the exact location and severity of the instability need to be established. At present, the mechanical properties of individual spinal motion segments cannot be measured in vivo because MRI and X-ray images can only provide an estimate of the mechanical properties based on degeneration and instrumented spinal manipulation and intraoperative measurement devices can only obtain the mechanical properties of the entire spine; although these devices typically apply a transverse or bending force to the spinous processes and measure the deflection at the point of force application, they do not take into account that the load–displacement data of only one segment do not reflect the mechanical properties of this single segment, but of the tested as well as all adjacent segments.

* Corresponding author at: VU University, Faculty of Human Movement Sciences, Van der Boechorststraat 9, NL-1081 BT Amsterdam, The Netherlands.
*E-mail addresses:* j.h.van.dieen@vu.nl, j_h_van_dieen@fbw.vu.nl (J.H. van Dieën).

0021-9290/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2011.03.013