Available online at www.sciencedirect.com
SCIENCE DIRECT®
Clinical Biomechanics 20 (2005) 126–129
CLINICAL BIOMECHANICS
www.elsevier.com/locate/clinbiomech

The direction of progressive herniation in porcine spine motion segments is influenced by the orientation of the bending axis

Crystal D. Aultman, Joan Scannell, Stuart M. McGill *

Faculty of Applied Health Sciences, Department of Kinesiology, University of Waterloo, Waterloo, Ont., Canada N2L 3G1

Received 12 May 2004; accepted 20 September 2004

Abstract

Background. It has been shown that disc herniations are a cumulative injury created by repetitive flexion motion while under modest compressive loads. There is a lack of data linking the direction of nucleus tracking to the orientation of the bending motion axis. Our purpose was to determine if the direction that the nucleus tracks through the annulus during progressive herniation is predictable from the direction of bending motion (i.e. a specific side with posterio-lateral herniation).

Methods. Matched cohorts (nu = 16) of porcine cervical spine (C3/4 and C5/6) motion segments were potted in aluminum cups and bent at an angle of 30° to the sagittal plane flexion axis while under a sustained compressive load of 1472 N.

Findings. The direction of bending motion affected the tracking pattern of the nucleus through the annular fibres in a predictable pattern. Specifically, bending the motion segments at an angle of 30° to the left of the sagittal plane flexion axis biased the movement of the nucleus toward the posterior right side of the disc in 15 of the 16 specimens.

Interpretation. Based on this animal model, shown to have similar biomechanical behaviour to humans, the direction that the nucleus tracks through the annular fibres appears to be dependent upon the direction of bending motion. This may have implications on both herniation prevention and rehabilitation of posterio-lateral bulges and herniations.

Keywords: Herniation; Spine; Injury; Flexion

1. Introduction

Clinically, disc herniation is most commonly observed posteriorly or posterio-laterally (Cruess and Rennie, 1984; White and Panjabi, 1978). Although a consistent method for generating disc herniations has been established (Gordon et al., 1991; Callaghan and McGill, 2001), there is a lack of research documenting whether the type of motion can influence the direction that the nucleus tracks (i.e. posterio-lateral). Using cadaveric lumbar motion segments with intact passive tissues and facets, Adams and Hutton (1985) demonstrated that repetitively loading the spine results in delamination of the annulus. Specifically, when the spine is loaded asymmetrically, the nucleus tracks along a radial fissure formed in the contralateral corner of the disc suggesting that annular delamination is load/direction dependent. This phenomenon was demonstrated while motion segments were cyclically compressed at a predetermined flexion angle, therefore few specimens failed by disc prolapse. Callaghan and McGill (2001) determined that posterior disc herniations are consistently created with repetitive flexion under modest static compressive forces. Their data suggest that disc herniations are an injury that result from cumulative bending trauma and can initiate after only 5870 cycles of flexion/extension while under a compressive load of only 867 N. However, when the compressive load was increased to 1472 N, the incidence of disc herniations

* Corresponding author.
E-mail address: mcgill@healthy.uwaterloo.ca (S.M. McGill).

0268-0033/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2004.09.010

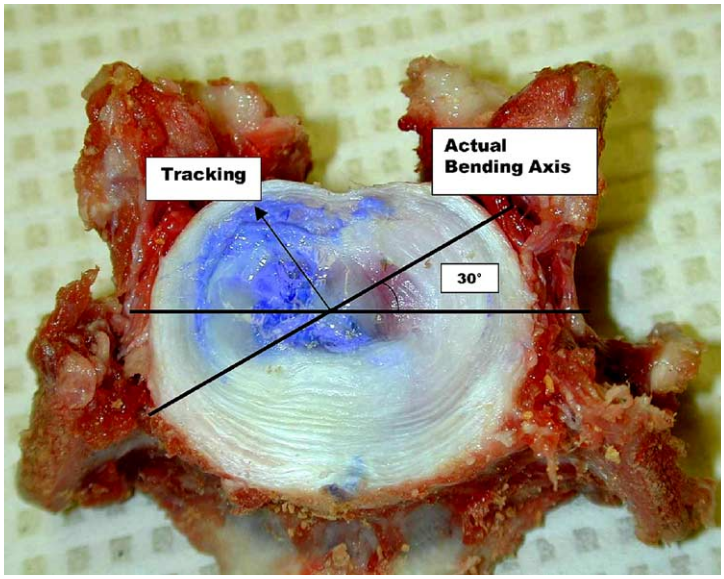

Fig. 1. Photograph of C4 sectioned from a C3/4 motion segment. Bending the motion segments about an axis oriented 30° to the left of the sagittal plane flexion axis resulted in the nucleus tracking toward the posterior right side of the disc.

Fig. 2. An industrial worker performing a repetitive task involving combined flexion with lateral bend is demonstrative of the complex motion pattern examined in the present study.

also increased and the extent of tissue damage was more severe. With this background, an asymmetrical loading pattern combined with repetitive flexion is needed to assess whether changing the bending axis influences the direction of progressive tracking. If so, this would provide evidence to justify specific primary and secondary prevention approaches together with specific motion based rehabilitation strategies.

The purpose of this study was to determine if the direction of nucleus tracking during progressive herniation is dependent upon (and therefore predictable from) the plane of bending motion. It was hypothesized that repetitively bending the motion segment oriented at the *x*-axis minus 30° (terminology according to Panjabi et al., 1974) would bias the progressive tracking of the nucleus towards the posterior right side of the disc. In orthopaedic terms, the motion was about the sagittal plane flexion axis that had been turned 30° (Fig. 1). The motion examined in the present study is a common movement in real working life as documented by Fathallah et al. (1998) and shown in Fig. 2.

2. Methods

Sixteen porcine cervical spines were obtained and frozen immediately post-mortem in doubled polyethylene bags at −20 °C. The spines were matched for age (approximately 6 months old), weight (80 kg), diet, and physical activity. Prior to testing, the specimens thawed for 12–15 h to ensure the disc had reached room temperature. They were then dissected into motion segments of two vertebrae (C3/4 and C5/6). The intervening disc, facet joints, and passive tissues of the two vertebrae remained intact. The data set consisted of 12 C3/4 and 4 C5/6 motion segments. Fixation of the specimens was achieved by four 18-gauge wires which were looped bilaterally around the anterior processes and the lamina and looped through holes in aluminum cups. A "pastry bag" was used to inject non-exothermic dental stone (Denstone®, Miles, South Bend, IN, USA) all around the base of the vertebra and within the cups to further prevent any motion at the cranial and caudal ends of the motion segments. Finally, a screw was also used to fasten the top aluminum cup to the cranial end of the motion segment, protruding a maximum of 1 cm into the centre of the vertebral body. To assist subsequent investigation of the direction of nucleus tracking, a solution of 0.25 mL barium sulphate (radio-opaque), 0.15 mL water, and 0.15 mL blue dye (Coomassie Brilliant Blue G-mix: 0.25% dye, 2.5% MeOH, 97.25% distilled water) was injected into the centre of the discs through the anterior annulus wall. Although radiographs were not obtained in this experiment, barium sulphate was included because this consistency and viscosity of solution was known to track through the annulus only if a fissure was present (Callaghan and McGill, 2001). To maintain hydration, the specimens were wrapped in bench-top paper, wet with a physiologic saline solution (0.9% NaCl), and enclosed in polythene film. The direction of nucleus tracking was documented from visual inspection and digital photographs of the discs after sectioning the motion segments.

A servohydraulic dynamic testing machine (model 8511, Instron Canada, Burlington, Ont., Canada) was used to apply a compressive pre-conditioning load of 300 N to all specimens for 15 min prior to testing. The pre-conditioning countered any swelling that had occurred post-mortem and due to freezing. During the preload, a custom jig (Callaghan and McGill, 2001) controlled using a servo-motor, found a position of zero torque, or elastic equilibrium, which was used as the zero position (neutral lordosis) for the passive and dynamic testing protocol. Each specimen underwent a passive range of motion test performed under 1472 N of compression. The passive test brought the specimens through five repeats of their passive range of motion at a rate of 0.5°/s. The axis for the range of motion was oriented 30° from the anatomical sagittal plane flexion/extension axis. Again using the Instron, a dynamic test repetitively bent 16 specimens (about the 30° axis) at a rate of 0.5 Hz for 6000 cycles while under 1472 N of compression. The bending 'elbow' of the angle vs. torque curve, corresponding to the point of increased stiffness in bending, was used as a limit for the range of motion in the dynamic test. The specimens were brought back to neutral (the position of elastic equilibrium) for each cycle.

3. Results

Bending the motion segments about an axis oriented 30° to the left of the sagittal plane flexion axis resulted in the focused nucleus tracking toward the posterior right side of the disc in 15 of the 16 trials (94%) (Fig. 1). Specifically, while 14 of the 15 were very distinct in the nucleus track, one of the 15 had a bulge as expected on the right posterio-lateral side of the disc, but with more diffuse leakage of the dye around the annulus. The one specimen that did not show a distinct track simply demonstrated general failure with leakage of the dye in all directions.

4. Discussion

These data suggest that the direction of progressive posterio-lateral herniation, at least in porcine segments, is dependent upon (and therefore predictable from) the direction of bending motion. Repetitively bending the motion segments at an angle of 30° to the left of the sagittal plane flexion axis biased the tracking of the nucleus toward the posterior right side of the disc.

Clearly, repetitive flexion under a modest compressive load remains a convincing mechanism for disc prolapse (Callaghan and McGill, 2001). The initiation and progression of a herniation involves the nucleus tracking through a fissure in each concentric layer of annular fibres as suggested by Adams and Hutton (1985) and seen in the present study. Discovering that the side that the nucleus tracks is dependent upon the direction of bending motion is of use in understanding injury mechanics (particularly progressive disc herniation) and therefore in developing methods of injury prevention. It is plausible that an observed posterio-lateral herniation or bulge on one side of the disc would be linked to dominant bending to the other side in real life (Adams and Hutton, 1985). Based on retrospective injury records, Fathallah et al. (1998) reported that industrial workers at high and medium risk of low back disorders performed complex motion patterns involving combined lateral and twisting velocities similar to the motion pattern examined in the present study.

The observation of one specimen that exhibited diffuse annular failure could have been due to several variables. It is possible that the quality of the disc was compromised and that undetected damage existed in this specimen prior to the experiment. It is unlikely that the other discs were damaged given their origin and similar behaviour.

The primary limitation of this study was the use of an animal model to portray the response of the human lumbar spine. Young, healthy, human cadavers matched for age, diet, weight, and physical activity are simply not available. However, the porcine spine appears to be a useful surrogate to the human lumbar spine in both anatomical features (Oxland et al., 1991) and biomechanical behaviour (Yingling et al., 1999). Although no study has examined the orientation of the annular fibres in pig discs, our hand-protractor measurements suggest they are similar. The similarities of a pig neck and human lumbar spine should not be surprising since a large extensor moment is required to hold up the cantilevered head of a quadruped which results in huge compressive forces on the cervical vertebrae similar to the compressive forces on the human lumbar spine from supporting the weight of the upper body and head. Pigs also exercise a 'rooting' behaviour hence the robust extensor anatomy and restricted motion similar to a human lumbar spine. In summary, a porcine cervical spine model provides a homogeneous subject sample for a matched group control study such as this and appears to have similar failure mechanics to a young adult human.

In conclusion, repetitive bending (flexion with some lateral bend) produces tracking of the nucleus toward the opposite posterior side of the disc. This information may be useful for both diagnostic and prevention issues and introduces a new question: If the direction that the nucleus tracks is dependent upon the direction of bending motion, can prophylactic motion patterns be defined that would slow the progression of a prolapsed disc to a herniation?

Acknowledgment

We would like to thank the Natural Science and Engineering Research Council of Canada for their financial support and Jeff Rice and Wendell Prime for their technical assistance.

References

Adams, M.A., Hutton, W.C., 1985. Gradual disc prolapse. Spine 10 (6), 524–531.

Callaghan, J.P., McGill, S.M., 2001. Intervertebral disc herniation: studies on a porcine model exposed to highly repetitive flexion/extension motion with compressive force. Clin. Biomech. 16, 28–37.

Cruess, R.L., Rennie, W.R.J., 1984. Adult Orthopaedics. Churchill Livingstone Inc., New York.

Fathallah, F.A., Marras, W.S., Parnianpour, M., 1998. The role of complex, simultaneous trunk motions in the risk of occupation-related low back disorders. Spine 23 (9), 1035–1042.

Gordon, S.J., Yang, K.H., Mayer, P.J., et al., 1991. Mechanism of disc rupture—a preliminary report. Spine 16 (4), 450–456.

Oxland, T.R., Panjabi, M.M., Southern, E.P., et al., 1991. An anatomic basis for spinal instability: a porcine trauma model. J. Orthop. Res. 9 (3), 452–462.

Panjabi, M.M., White III, A.A., Brand Jr., R.A., 1974. A note on defining body parts configurations. J. Biomech. 7 (4), 385–387.

White III, A.A., Panjabi, M.M., 1978. Clinical Biomechanics of the Spine. J.B. Lippincott Co., Philadelphia.

Yingling, V.R., Callaghan, J.P., McGill, S.M., 1999. The porcine cervical spine as a reasonable model of the human lumbar spine: an anatomical, geometric, and functional comparison. J. Spinal Disorders 12, 415–423.