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The influence of static axial torque in combined loading on intervertebral joint failure mechanics using a porcine model

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Abstract

Background. The spine is routinely subjected to repetitive combined loading, including axial torque. Repetitive flexion–extension motions with low magnitude compressive forces have been shown to be an effective mechanism for causing disc herniations. The addition of axial torque to the efficacy of failure mechanisms, such as disc herniation, need to be quantified. The purpose of this study was to determine the role of static axial torque on the failure mechanics of the intervertebral joint under repetitive combined loading.

Methods. Repetitive flexion–extension motions combined with 1472 N of compression were applied to two groups of nine porcine motion segments. Five N m of axial torque was applied to one group. Load–displacement behaviour was quantified, and planar radiography was used to document tracking of the nucleus pulposus and to identify fractures.

Findings. The occurrence of facet fractures was found to be higher ($P = 0.028$) in the axial torque group (7/9), compared to the no axial torque group (2/9). More hysteresis energy was lost up to 3000 cycles of loading in the axial torque group ($P < 0.014$). The flexion–extension cycle stiffness was not different between the two groups until 4000 cycles of loading, after which the axial torque group stiffness increased ($P = 0.016$). The percentage of specimens that herniated after 3000 cycles of loading was significantly larger ($P = 0.049$) for the axial torque group (71%) compared to the no axial torque group (29%).

Interpretation. Small magnitudes of static axial torque alter the failure mechanics of the intervertebral disc and vertebrae in combined loading situations. Axial torque appears to accelerate the susceptibility for injury to the intervertebral joint complex. This suggests tasks involving axial torque with other types of loading, apart from axial twist motion, should be monitored to assess exposure and injury risk.

Keywords: Axial torque; Spine; Herniation; Injury; Cumulative loading

1. Introduction

Axial torques (AT) are experienced daily by the lumbar spine while performing domestic, athletic, and industrial tasks. Both axial rotation (Kelsey et al., 1984; Marras et al., 1993; Punnet et al., 1991) and cumulative compressive loading (Jager et al., 2000; Kumar, 1990; Norman et al., 1998) have been identified in epidemiologic studies as significant risk factors in developing low back injuries and/or pain. Damage to a facet joint (McCall et al., 1979; Schwarzer et al., 1994) or the intervertebral disc (IVD) (Ito et al., 1998; Boos et al., 2000) has the potential to cause low back pain. However, the onset of IVD injury/degeneration does not always coincide with onset of pain (Boden et al., 1990; Jensen et al., 1994), nor is there always diagnostic evidence to correlate damage with painful facet joints (Schwarzer et al., 1995b).

Several researchers have examined the partitioning of the AT resistance between the IVD and facets. Various

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magnitudes of applied AT have been investigated: Farfan (1969) average maximum torque ranging from 23.7 to 32.7 N m, Krismer et al. (1996) ≈2–8.5 N m, Pearcy and Hindle (1991) between 12 and 25 N m, and Adams and Hutton (1981) 18–31.6 N m (with different grades of disc degeneration and varied compression between 377.8 and 624.5 N). Farfan (1969, 1970) concluded that AT damages the IVD prior to causing any bony damage. Krismer et al. (1996) reported that intact annulus fibres are more capable to restrict small axial torques than facet joints, and concluded AT is important in the development of disc degeneration. However, several researchers found that combined loading of AT and compression damages the facet joints and is not compromising to the structural integrity of the IVD (Adams and Hutton, 1981; Pearcy and Hindle, 1991). The opinion of these researchers was that intact facets protect the IVD from an AT load, so facet fracture must precede disc herniation. The potentially controversial findings regarding the role of AT in IVD failure mechanics are likely due to the use of different loading scenarios (i.e. with/without compression).

Risk factors identified for low back disorders in industry do not usually separate the effects of trunk AT from active trunk axial rotation; since these variables are inherently dependent (AT creates the rotation). Axial rotation has been reported to increase the risk of developing a low back disorder (i.e. herniation) when incorporated into lifting scenarios, or is a component of the required work posture (Kelsey et al., 1984; Marras et al., 1993; Punnet et al., 1991). Conversely, axial rotation was not associated with increased risk for developing a low back disorder when performed independent of lifting (Kelsey et al., 1984). The mechanism underlying the transformation of AT/axial rotation from benign to malignant when combined with other types of loading is unknown. Further, the structures involved in the failure resulting from combined loading with AT need to be identified. This is crucial information in the decision to create and implement guidelines governing the permissible repetitive exposure limit to AT, and to the diagnosis and subsequent treatment/rehabilitation assigned for the injuries.

Using porcine specimens, Callaghan and McGill (2001) demonstrated that herniation can be reliably created with modest levels of compression (867 N and 1472 N) with highly repetitive flexion–extension motions, without damaging the facet joints. The question of whether low magnitudes of AT in addition to repetitive combined loading impacts the failure mechanics remains. Researchers have speculated that three axes of combined loading could increase the vulnerability of the IVD to injury (Ahmed et al., 1990; Pearcy and Hindle, 1991), and that such complex modes of loading more closely mimics loading in vivo (Pearcy and Tibrewal, 1984). Yet, three axes of combined loading, repetitive or acute, have rarely been investigated. A repetitive loading example was conducted by Gordon et al. (1991) who herniated all 14 tested functional spinal units (FSU) with the application of two static positions (7° flexion and >3° axial twist) combined with repetitive compression (1334 N), to an average of 40 000 loading cycles. Haberl et al. (2004) loaded specimens three times (30 s duration) with combinations of 200 N of compression, and up to 6 N m of flexion or extension, and 12.5 N m of static AT, and tracked the resulting kinematics, but did not report injury data. The mechanism of how chronic exposure to AT contributes to intervertebral joint failure mechanics remains poorly understood. The purpose of this study was to investigate the role of static AT, coupled with highly repetitive flexion–extension motions and static compression, on FSU failure mechanics. It was hypothesized that the addition of AT would not effect the onset, mode, or characteristics of specimen failure.

2. Methods

2.1. Specimen preparation

Eighteen C3–C4 porcine cervical motion segments were obtained from a common source to control for physical activity, diet, and age prior to death. Ideally, human lumbar specimens would be used in this study, but suitable human specimens are scarce and difficult to obtain. Given the functional, geometrical, and anatomical similarities between porcine cervical and human lumbar FSUs, porcine specimens were used as a model of human tissues in this study of injury mechanics (Oxland et al., 1991; Yingling et al., 1999). The porcine specimens were prepared, mounted and loaded (1472 N compression) as described in Callaghan and McGill (2001). Briefly, the specimens were thawed, dissected to osteo-ligamentous FSUs, and fixed into custom aluminum cups using wire looped around the laminae and anterior processes, screws into the vertebral bodies, and embedded in dental plaster. The specimens were wrapped with saline soaked plastic-backed cloth and plastic wrap to ensure continuous hydration. Approximately 0.7 cm^3 of barium sulfate radio-opaque mixed with blue dye (Coomassie Brilliant Blue G-mix: 0.25% dye, 2.5%MeOH, 97.25% distilled water) was injected into the IVD prior to testing. This solution has proved effective for permitting the documentation of nuclear material tracking using radiography (Callaghan and McGill, 2001). The 1472 N compressive load used in this study is approximately 14–22% of the average compressive strength of porcine cervical specimens reported in the literature. Aultman et al. (2004) and Gunning et al. (2001) found the average compressive strength of C3/4 and C5/6 specimens to be between approximately