FACET JOINT CAPSULE STRAINS OF HUMAN LUMBAR SPINE SPECIMENS DURING PHYSIOLOGICAL MOTIONS

Allyson Ianuzzi, Jesse S. Little, Jonathan B. Chiu
Department of Biomedical Engineering
Stony Brook University
Stony Brook, NY

Avi Baitner
Department of Orthopaedics
Stony Brook University
Stony Brook, NY

Greg Kawchuk
Department of Kinesiology
University of Calgary
Calgary, Alberta
Canada

Partap S. Khalsa
Department of Biomedical Engineering
Stony Brook University
Stony Brook, NY

ABSTRACT

The lumbar facet joint capsule is an innervated structure thought to serve proprioceptive functions. To examine the facet capsule's potential proprioceptive role, relationships between intracapsular strain and relative spine position were examined in human cadaveric lumbar spine specimens using a custom displacement-controlled apparatus. Specimens were potted and actuated under displacement control for testing during physiological motions of extension (E), flexion (F), left lateral bending (LB), and right lateral bending (RB). Differences in the developed moment, intervertebral angle (IVA), and principal strain at facet joint capsules were examined. The developed moments and IVAs increased monotonically with increasing displacements; relationships were highly correlated during all four motion types. Although variable among specimens, principal strains also increased monotonically during E and F, but were more complex during lateral bending. At a given joint level, the absolute magnitudes of IVA and strain were largest during the same motion type. Since distinct patterns in principal strains and IVA were identified during physiological motions, the current study lends support to the theory that lumbar facet joint capsules can function proprioceptively.

INTRODUCTION

It is relatively well established that the lumbar facet joint capsule is innervated by mechanoreceptors (McLain & Pickar 1998), which could provide information regarding facet joint movement and/or relative position. For the facet capsule to function proprioceptively during spine motions, the capsule must be loaded such that intracapsular strains would be proportional to the spine's position.

METHODS

Unembalmed, human, ligamentous lumbar spine specimens (n = 7) were potted and actuated under displacement control at T_{12}. The T_{12} vertebral body was connected to a rod via a rigid U-shaped coupling with a pin through the middle of the vertebral body, allowing a single degree of freedom. The coupling was in series with a force transducer mounted to a linear actuator by a low friction universal joint. Thus, as the spine was actuated, loads were applied without inducing a moment at the point of application.

Spines were tested in flexion (F), extension (E), left lateral bending (LB), and right lateral bending (RB) (10 cycles at displacements of 10 – 40 mm at 10mm/s). Biaxial inclinometers mounted on adjacent vertebrae measured vertebral body rotations for determination of intervertebral angulations (IVA). Capsule plane strains (Lagrangian large strain formulation) were measured by optically tracking, with two CCD cameras, the displacements of infrared reflective markers (1 mm radius) glued to capsule surfaces. Markers were typically placed as 3 x 3 arrays forming four quadrilaterals, from which plane and principal strains were calculated relative to the neutral vertical position of the spine. To account for rotation of the plane, an extension of the method of Hoffman & Grigg (1984) was used. Principal strains E1 and E2 (whose orientations were closest to the X- and Y-axis, respectively) were organized as maximum (predominantly tensile) and minimum (predominantly compressive) strains (denoted $\overline{E}1$ and $\overline{E}2$, respectively). Statistical differences ($p<0.05$) in moment, IVA, and strain were assessed across joint levels and displacement using ANOVA with post-hoc Tukey tests and pair-wise comparison of linear regression lines (CLRL, $\alpha = 0.05$).

RESULTS

Mean moments developed at each facet joint increased monotonically with increasing displacements (Fig. 1A). Joint moments significantly increased with increasing displacements ($p < 0.001$); the differences were significant where the respective displacement magnitudes differed by 20 mm or greater ($p < 0.05$). Mean moment-displacement relationships were highly correlated (R^2 range 0.919 – 0.990) and were statistically different among joint levels ($p < 0.05$).

During E and F, the IVAs at L_5-S_1 were largest in absolute magnitude (Fig. 1B). At a given joint level, IVA increased monotonically with increasing displacements ($p < 0.05$); significantly larger IVAs typically occurred at larger displacements in the caudad motion units ($p < 0.05$). At a given displacement, the IVAs among the joint levels were significantly different ($p < 0.05$), where larger IVAs

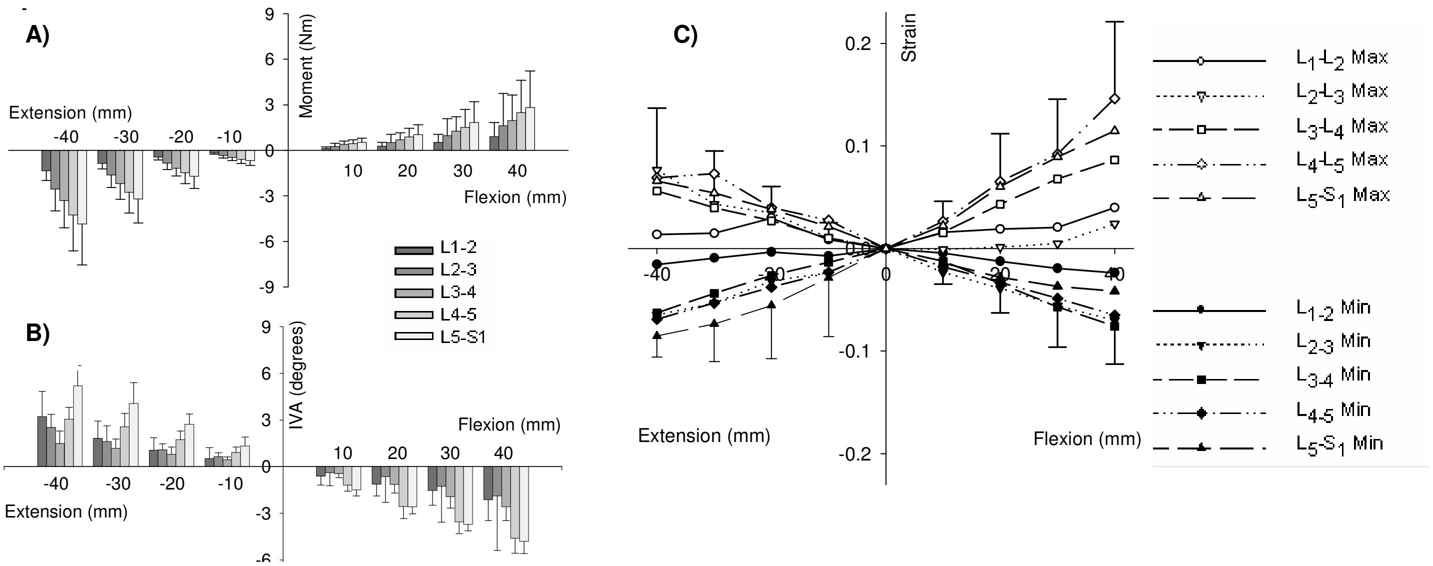

Figure 1. A) Moments and B) Intervertebral angles (IVA) increased monotonically at a given joint level with increasing displacements during extension and flexion. C) Mean Maximum and Minimum Principal Strains ($\bar{E}_1$ and $\bar{E}_2$, respectively; refer to text for definition) during extension and flexion, from left facet capsules, were highly correlated with displacement.

were typically measured at the more caudal joints than at the more cephalic ($p < 0.05$). During LB and RB, the IVAs at $L_{3\text{-}4}$ were largest in absolute magnitude. At a given joint level, IVA increased in magnitude with increasing displacements ($p<0.005$); these differences were typically significant when the displacement differed by 20 mm or greater ($p < 0.05$). At a given displacement, mean IVAs differed among joint levels ($p<0.05$); IVA at $L_{3\text{-}4}$ was typically larger compared to other joint levels ($p < 0.05$). Mean IVA-displacement relationships during all motions were highly correlated (R^2 range 0.927 – 1.0).

Designating the two principal strains as $\bar{E}_1$ and $\bar{E}_2$ was highly consistent with classification of strain according to direction (i.e., E1 and E2). During compressive motions, a large percentage of $\bar{E}_2$ was oriented closest to the Y-axis, while $\bar{E}_1$ was typically oriented closest to the X-axis. The opposite was true during tensile motions.

On average, the absolute magnitudes of the principal strains increased with larger displacements (Fig. 1C). During E, mean $\bar{E}_2$ was larger in absolute magnitude at the L_5-S_1 capsules compared to the more cephalic joint capsules (CLRL, $p < 0.05$). At a given joint level, mean $\bar{E}_2$ was larger in absolute magnitude than $\bar{E}_1$. During F, $\bar{E}_1$ was significantly larger at the more caudal joint capsules compared to the more cephalic capsules (CLRL, $p < 0.05$).

During lateral bending, facet capsule principal strains were more complex. On the left side of the spine during RB, $\bar{E}_1$ at $L_{4\text{-}5}$ was significantly larger than $L_{1\text{-}2}$. $L_{2\text{-}3}$ $\bar{E}_1$ was significantly smaller in absolute magnitude than those at all other joint levels (CLRL, $p < 0.05$). During RB on the left side of the spine, $\bar{E}_2$ at L_5-S_1 was significantly smaller in absolute magnitude compared to the three more cephalic joint capsules (CLRL, $p < 0.05$).

On the right side of the spine, mean $\bar{E}_1$ in the more caudal joints ($L_{3\text{-}4}$,- L_5-S_1) was larger in magnitude during LB compared to RB, while the opposite was true for the cephalic joints ($L_{1\text{-}2,}$ $L_{2\text{-}3}$); these differences were not always significant. Conversely, mean $\bar{E}_2$ in the more caudal joint capsules were larger in absolute magnitude during RB compared to LB, while the opposite was true for the cephalic joints. Again, these differences were not always significant.

The types of motion that created the largest IVA were the same motion types that created the largest principal strains. At the more cephalic joint levels ($L_{1\text{-}2}$ - $L_{3\text{-}4}$), the largest IVAs and principal strains occurred during lateral bending. At the caudal two motion units ($L_{4\text{-}5}$ and L_5-S_1), maximum IVA and strain occurred during E/F.

DISCUSSION

During physiological spine motions, human lumbar facet joint capsules undergo substantial plane strains (e.g., over 20% on average from full E to full F in the most caudal lumbar joint capsules). Capsule strains during LB and RB demonstrated relative mirror symmetry. Because human facet joint capsules are innervated with low threshold mechanoreceptors and nociceptors (McLain & Pickar, 1998), it suggests that they could serve proprioceptive functions. In animal studies of knee joint capsules, stretch-activated mechanoreceptors had relatively low thresholds (~ 1 – 5 kPa) (Khalsa et al., 1996). It is likely that this threshold is achieved during human physiological spine motions (Khalsa et al., 2002). To the extent that human facet capsule afferents are similar to animal joint capsule afferents, it follows that human capsule afferents are stimulated during physiological spine motions. The consistent pattern of facet capsule strains associated with lumbar motions presented in the current study provides biomechanical evidence supporting a proprioceptive theory for facet capsules in human lumbar spines.

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