In-vivo Dynamic Changes of Dimensions in the Lumbar Intervertebral Foramen

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Introduction: Lumbar intervertebral foramen (LIVF) stenosis is a common cause of nerve root compression. The dimensions of the LIVF change constantly during daily activities inducing mechanical stimulus on pain-sensitive structures (nerves, ligaments, intervertebral discs) [1]. Previous studies have indicated position-dependent changes in the LIVF dimensions during static end-range flexion-extension postures [2]. However, the dynamic in-vivo changes in LIVF dimensions during flexion and extension are still unclear. Therefore, the purpose of this study was to investigate the in-vivo dynamic changes in cross-sectional measurements of the LIVF during a weight-lifting activity.

Methods: Ten asymptomatic subjects (5 males and 5 females, aged 40 to 60 years old) were recruited for this study. 3D vertebral models of lumbar segments L2 to S1 were constructed for each subject from MR images [3]. The lumbar spine was then imaged using a dual fluoroscopic system as the subject performed lumbar extension, from a flexion position of ~45º to a maximal extension position, with each hand holding an 8 pound dumbbell (Fig. 1A). The fluoroscopes captured the dynamic positions of the vertebrae at 30 frames per second with an 8 milli-second pulse. The 3D vertebrae models and the fluoroscopic images were then used to reproduce the in-vivo vertebral positions along the motion path (Fig. 1B&1C). LIVF models were obtained using the Boolean operator after the LIVFs were fully filled with cylinders in solid modeling software (Rhinoceros) (Fig. 2A&2B). The LIVF dimensions (area, height, and width) were measured on the pedicle cutting plane, which was the narrowest cross-sectional area of the LIVF (Fig. 2C&2D). The dimensions for each intervertebral level were averaged from both sides of the foramen. ANOVA and post-hoc analysis were used to analyze the LIVF dimensions across lumbar segments. A statistical difference was achieved when p < 0.05.

Results: During the weight-lifting activity, LIVF area and width decreased significantly at all levels except L5/S1 (p < 0.05) (Fig. 3A&3C). From the starting position of ~45º flexion to an upright position, significant differences in LIVF area were found between any two segments except for L2/3 and L3/4 (the upper lumbar spine) (p < 0.05). Conversely, from an upright position to the ending position of maximal extension, significant differences were found between any two segments except for L4/5 and L5/S1 (the lower lumbar spine) (p < 0.05). LIVF height remained relatively constant at all segments during the dynamic activity (Fig. 3B).

Discussion: This study is the first to investigate in-vivo dynamic changes in the dimensions of LIVF during a functional activity. Results show that the foramen area decreases during a weight-lifting activity at levels L2/3, L3/4, and L4/5. This decrease in area is driven by a decrease in width as height remains relatively constant throughout the motion. These findings support the concept of dynamic LIVF stenosis. L5/S1 also demonstrates distinct characteristics from the other levels as foramen area, height, and width
remain relatively constant throughout the activity. The results provide further insight into in-vivo dynamic function of the lumbar spine.

Significance: Current findings support the concept of dynamic LIVF stenosis. L5/S1 also demonstrates distinct characteristics from the other levels as foramen area, height, and width remain relatively constant throughout the activity.

Fig. 1: A) Experimental setup of the dual fluoroscopic system. B) Virtual recreation of the experimental set-up in solid modeling software allows vertebrae poses to be reproduced using an image matching technique. C) Resulting positions of the 3D lumbar vertebrae models during the lifting motion.
Fig. 2: A) The LIVFs were fully filled with a cylinder. B) The LIVF model was obtained using the Boolean operator. C) The narrowest cross-sectional area of the LIVF was obtained from the pedicle cutting plane. D) LIVF dimensions include: the height, which was defined as the longest line between the cranio-caudal boundary (green line); the width, which was defined as the shortest line between the postero-inferior corner of the proximal vertebrae and the opposing boundary (blue line); and the area, which was drawn anatomically according to the LIVF bony outline (red outline).
Fig. 3: The LIVF dimensions (area, height, and width) during the weight-lifting activity.

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