Lumbar response to flexion-compression in cyclic and quasi-static loading in intervertebral discs

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I. INTRODUCTION

Repeated combined flexion-compression loading is associated with acute and chronic lumbar injury [1-2]. Those exposed to whole-body vibration, such as helicopter pilots, long duration truck drivers and others [3], are at a higher risk for developing lower back pain. Currently, it is unknown whether the cyclic mechanism alone plays a role in the creep response and eventual degeneration of intervertebral discs (IVDs) or if there exist quasi-static conditions that produce a similar response and/or injury pattern. This study compares lumbar spinal creep response under oscillatory and quasi-static flexion-compression.

II. METHODS

Porcine lumbar functional spinal units (FSUs) were loaded in a biaxial testing apparatus with either an oscillatory or a quasi-static flexion-compression loading profile. In order to produce a similar creep response, the applied peak stress was held constant between oscillatory and quasi-static tests, but the flexion angle was varied. Tests were carried out in an environmental chamber to simulate *in vivo* temperature and humidity conditions. FSUs from three porcine lumbar spines were used for seven total tests. One FSU from each spine was used for oscillatory testing, in which a 1 Hz sinusoidal compression wave and an offset 1 Hz flexion ramp was applied to approximate *in vivo* occupational loading exposures for high-speed watercraft occupants [4]. For oscillatory tests, peak flexion angle for all tests was 6° and peak loads were 1200 N, 1370 N and 1400 N. The remaining FSUs were subject to quasi-static loading in which the flexion angle was held at either 3°, 5° or 5.5° under constant peak compressive axial force, scaled by endplate area to apply equivalent stress as the paired oscillatory test from the same donor spine. FSUs tested in the oscillatory loading profile were loaded until an inflection was observed in the displacement-logtime history to ensure that creep response analysis was prior to incipient injury. Subsequent quasi-static tests were loaded for the same duration as the paired oscillatory test. To smooth oscillations from cyclic data and find average displacement, the data were filtered with an 8^{th} order phaseless low-pass Butterworth filter with a 0.1 Hz cutoff frequency. Engineering strain was calculated for each FSU based on endplate-to-endplate (EP) distance adjacent to the IVD. EP distances were measured from high-resolution computed tomography scans. Creep profiles were compared using strain time histories. The FSU experimental response was modeled as an exponential function and percent difference was calculated for quantitative comparison of curves.

III. INITIAL FINDINGS

Creep response differed based on loading profile. An FSU with 3° flexion under quasi-static loading showed less strain compared to an FSU under oscillatory loading with 6° flexion, with a 36.7% percent difference between curves (Fig. 1A). At 5.5° quasi-static flexion, the creep response was greater than that seen in oscillatory loading and percent difference between curves decreased to 17.7% (Fig. 1B). These findings implied that there existed an angle between 3° and 5.5° that closely matched the oscillatory profile. Creep profiles showed similar behaviour between oscillatory and quasi-static testing with a 5° flexion angle (Fig. 2) resulting in 12.97% and 0.94% percent difference for two quasi-static tests compared to the oscillatory test. All curve fits had an R^2 value of 0.92 or greater.

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IV. DISCUSSION

These results imply that there exists quasi-static flexion and compression parameters that can simulate oscillatory creep behaviour. In this test series, applied peak stress was held constant between specimens from the same spine, while the quasi-static flexion angle was iteratively tested to relate resulting creep profiles, which was found to be 83% of the maximum oscillatory flexion. It is likely that there exists a quasi-static stress parameter at maximum flexion that would express a similar creep profile to Fig. 2. In caprine IVDs loaded with pure axial compression, similar deformation magnitude between oscillatory and quasi-static testing was also found [5]. Variation in creep between specimens with the same loading profile could be due to variation in stiffness between discs of different regions in the lumbar spine. The similarity in primary creep profiles between oscillatory and quasi-static loads suggests that superimposed oscillations in compression and flexion are a second order effect of creep while other processes, such as water flow from the disc, could be the primary effect. Thus, the oscillatory loading profile may not be the principal driver of creep and lumbar injury risk but rather other potential factors, such as the loading level and duration of loading, may play a significant role.

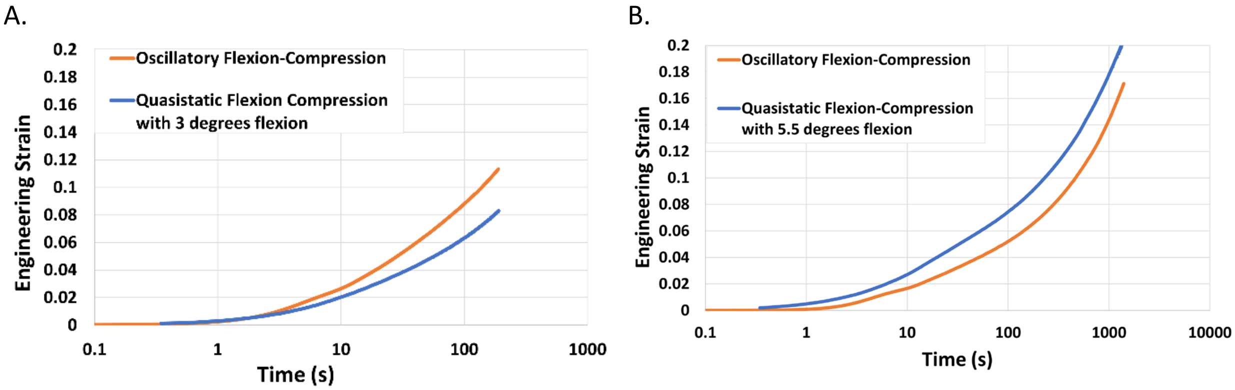

Fig. 1. Strain in IVDs under oscillatory (orange, n=1) and quasi-static (blue, n=1) loading. A: FSUs under 2.88 MPa stress with quasi-static test under compressive force of 1345 N with 3° flexion. B: FSUs under 2.05 MPa stress with quasi-static test under compressive force of 1230 N with 5.5° flexion.

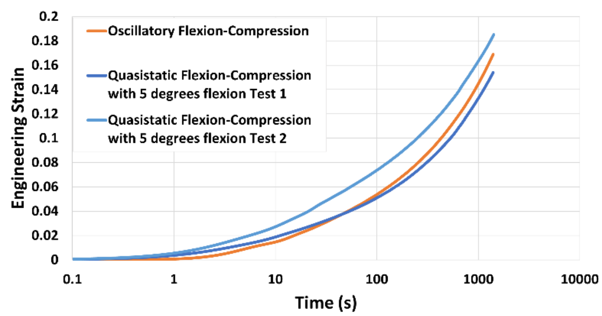

Fig. 2. Strain in IVDs under oscillatory (solid orange) and quasi-static loading (solid blue) under 2.05 MPa of stress with quasi-static tests loaded to 1336 N and 1438 N while held at 5° flexion.

V. REFERENCES

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