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Prior storage conditions and loading rate affect the *in vitro* fracture response of spinal segments under impact loading☆

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ABSTRACT

Traumatic injuries of the spine are mostly the consequence of rapid overload e.g. impact loading. *In vitro* investigations on this topic usually encompass biomechanical testing using frozen/thawed specimens and employ quasi-static loading conditions. It is generally accepted that a freezing/thawing cycle does not alter mechanical properties for slow loading rates. However, this has never been investigated for high impact velocities. In order to assess the effects of freezing/thawing and the influence of different impact velocities, we loaded 27 fresh and 15 frozen/thawed cadaveric rabbit spinal segments (intervertebral disc with one third of the adjacent vertebrae) with different impact energies and velocities using a custom-made, dropped-weight loading device. Endplate fractures were assessed by micro-CT scans. Specimen dimensions (disk, bone, and total height) and vertebrae bone density (BV/TV) were compared pre- and post-trauma. Energy absorption by spinal segments was quantified by measuring the initial ball rebound. We found that freezing/thawing increased endplate fracture frequency and decreased the energy absorption of the segments. Higher impact velocities increased the energy absorption, while higher impact energy increased both energy absorption and fracture frequency. Two conclusions are drawn: first, under impact loading, freezing alters permanently the biomechanical response, and second, for different impact velocities, different fracture initiation mechanisms apply. Therefore, quasi-static loading of frozen/thawed spinal segments is not a valid model for traumatic endplate injuries. However, caution should be exercised in extrapolating these findings to human vertebrae until tests on larger vertebrae are performed.

1. Introduction

Rapidly acting forces are the cause of most human injuries, including spinal injuries (Roaf, 1960). Despite the immense clinical significance of spinal injuries, segmental biomechanics have been insufficiently analyzed under dynamic loading (El-Rich et al., 2009). For the study of vertebral trauma, usually frozen/thawed cadaveric material is subjected to quasi-static loading conditions until failure. However, there are two problems linked to this approach: (i) the effects of a freezing/thawing cycle of spinal specimens when subsequently subjected to high-rate loading are rarely investigated and (ii) the nature of quasi-static loading conditions differs essentially from that of high-rate loading (Ochia et al., 2003).

A number of studies demonstrated that freezing/thawing cycles did not influence biomechanical testing when quasi-static loading conditions were used (Goh et al., 1989; Panjabi et al., 1985; Pelker et al., 1984; Hamer et al., 1996; Van Haaren et al., 2008, Kang et al., 1997), but the effects of high impact velocities remain unclear. *In vitro* experiments confirm the pivotal role of impact velocities on the characteristics of the resulting spinal injuries. Ochia et al. (2003) reported higher dynamic failure loads for human lumbar vertrebrae . Tests on cadaveric calf lumbar spines revealed that, for the same energy and direction of impact, a high impact loading rate produces fractures with significant encroachment of the spinal canal in contrast to minimal encroachment for fractures at a low loading rate (Tran et al., 1995). Tran et al. suggest that the extent of bursting of the vertebra depends on the rate of pressurization of the body, which could be related to the rate at which the load is applied. In a porcine model, failure at low loading rates occurred exclusively in the endplate whereas failure of the vertebral body appeared with

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