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Basic Science

Effects of acceleration level on lumbar spine injuries in military populations

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Abstract

BACKGROUND CONTEXT: Clinical studies have indicated that thoracolumbar trauma occurs in the civilian population at its junction. In contrast, injury patterns in military populations indicate a shift to the inferior vertebral levels of the lumbar spine. Controlled studies offering an explanation for such migrations and the associated clinical biomechanics are sparse in literature.

PURPOSE: The goals of this study were to investigate the potential roles of acceleration loading on the production of injuries and their stability characteristics using a human cadaver model for applications to high-speed aircraft ejection and helicopter crashes.

STUDY DESIGN: Biomechanical laboratory study using unembalmed human cadaver lumbar spinal columns.

METHODS: Thoracolumbar columns from post-mortem human surrogates were procured, x-rays taken, intervertebral joints and bony components evaluated for degeneration, and fixed using polymethylmethacrylate. The inferior end was attached to a platform via a load cell and uniaxial accelerometer. The superior end was attached to the upper metal platform via a semi-circular cylinder. The pre-flexed specimen was preloaded to simulate torso mass. The ends of the platform were connected to the vertical post of a custom-designed drop tower. The specimen was dropped inducing acceleration loading to the column. Axial force and acceleration data were gathered at high sampling rates, filtered, and peak accelerations and inertia-compensated axial forces were obtained during the loading phase. Computed tomography images were used to identify and classify injuries using the three-column concept (stable vs. unstable trauma).

RESULTS: The mean age, total body mass, and stature of the five healthy degeneration-free specimens were 42 years, 73 kg, and 167 cm. The first two specimens subjected to peak accelerations of approximately 200 m/sec^2 were classified as belonging to high-speed aircraft ejection-type and the other three specimens subjected to greater amplitudes (347–549 m/sec^2) were classified as belonging to helicopter crash-type loadings. Peak axial forces for all specimens ranged from 4.8 to 7.2 kN. Ejection-type loaded specimens sustained single-level injuries to the L1 vertebra; one injury was stable and the other was unstable. Helicopter crash-type loaded specimens sustained injuries at inferior levels, including bilateral facet dislocation at L4–L5 and L2–L4 compression fractures, and all specimens were considered unstable at least at one spinal level.

CONCLUSIONS: These findings suggest that the severity of spinal injuries increase with increasing acceleration levels and, more importantly, injuries shift inferiorly from the thoracolumbar junction to lower lumbar levels. Acknowledging that the geometry and load carrying capacity of vertebral bodies increase in the lower lumbar spine, involvement of inferior levels in trauma sparing the superior segments at greater acceleration inputs agree with military literature of caudal shift in injured levels. The present study offers an experimental explanation for the clinically observed

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Keywords: Acceleration level; Axial loading; Drop tower technique; Lumbar spine; Stability

Introduction

An important objective of clinical and descriptive or epidemiologic studies is to determine the role of anatomical, functional, structural, demographic, and anthropometric factors on injuries or dysfunctions from field observations and advance biomechanical postulates. In the civilian domain and specific to the spine, motor vehicle and fall-related events have been analyzed for vertical loading-induced compressive and burst fractures [1–3]. Laboratory investigations applying axial loading to post-mortem spinal preparations have focused on confirming/delineating the underlying mechanisms of trauma, describing tolerance, deriving injury criteria, designing stability imparting devices for treatment, and developing manikins for injury assessment and mitigation [4–7].

Military populations have received relatively less research attention, although improvements have been made in areas such as aircraft ejection and crashworthy seats and restraints to mitigate spinal injuries. A fundamental difference in the external insult pattern between civilian and military environments is the magnitude of load application. Greater amplitudes are associated in military incidents and often cited examples include high-speed aircraft ejection and helicopter crashes. Reported peak accelerations are 140 to 160 m/sec^2 in high-speed aircraft ejection [8] and 320 to 400 m/sec^2 in helicopter crashes [9]. It is well known that the responses of the human spinal column depend on the nature of the external insult and this includes rate of loading. Although high-rate loading studies using human cadaver spines exist, rates achieved in these studies are lower than those from high-speed aircraft ejection and helicopter crash events. Thus, the aim of this study was to investigate the roles of clinical and biomechanical variables using a human cadaver model as applied to high-speed aircraft ejection and helicopter crash events.

Methods

This study was conducted after obtaining approvals from the Local Institutional Review Board. The study was funded in part by the US Office of Naval Research. Thoracolumbar spinal columns were procured and x-rays were taken to ensure the absence of pre-existing trauma. Intervertebral joints and bony components were evaluated for degeneration: facet joints and discs were examined for arthrosis, endplate sclerosis, and decrease in disc height, and bony components were examined for osteophytes. All specimens were isolated at T12 and L5 levels and fixed at the ends using polymethylmethacrylate (PMMA). The mid-plane of the L2–L3 disc was maintained horizontal. The prepared specimen was connected to the testing device as follows [10].

The inferior PMMA was rigidly attached to a load cell (Denton Inc., MI, USA), mounted onto the metal platform of the testing device fixed with an uniaxial accelerometer. This formed the lower fixation for the preparation. The superior PMMA contacted an upper metal platform via a cylinder (Fig. 1). The apex of the cylinder initially contacting the superior end was aligned 35 mm anterior to the posterior longitudinal ligament at the L2–L3 disc. The specimen was pre-flexed with 5 Nm. A 32-kg mass was added to simulate torso mass. The preparation was held in place by a cable connecting the two metal platforms. They were connected to the vertical track of the drop tower using independent carriages. The specimen along with the platforms was dropped to sustain the impact loading from the inferior end of the lumbar column.

A digital data acquisition system (DTS systems Inc., CA, USA) was used to gather signals at a sampling frequency of 12,500 Hz. Accelerations and forces were processed using class 60 low-pass Butterworth filter. Peak forces during the loading phase were extracted from load cell records, which were compensated for inertia effects with acceleration data. Data were compared based on peak accelerations and forces. Lateral and anteroposterior x-rays were obtained after the test. Computed tomography scanning was performed (Siemens Inc., Washington, DC, USA), and sagittal reconstructed images were obtained. Injuries were classified using the three-column concept and instabilities were assessed on a specimen-by-specimen basis [11].

Results

The mean±one standard deviation data for age, total body mass, stature, and body mass index of the five specimens (three males, two females) were 42±12 years, 73±12 kg, 167±7 cm, and 26±2.3 kg/m^2, respectively. The average height of the exposed free length of the prepared column was 183±7.1 mm. Specimen-by-specimen data are included (Table 1). Peak accelerations ranged from 182 to 549 m/sec^2. Peak axial forces ranged from 4.8 to 7.2 kN. These data are included (Table 2) for each specimen. Specimens 1 and 2 sustaining peak accelerations of 182.1 and 218.1 m/sec^2 were classified as belonging to high-speed aircraft ejection-type loadings and specimens 3 to 5 sustaining 347.9 to 549.2m/sec^2 were classified as belonging to helicopter crash-type loadings. Peak axial forces for high-speed aircraft ejection-type loadings ranged from 4.8 to 5.6 kN. Peak forces for helicopter crash-type loadings