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Estimation of cervical spine internal loads with the use of validated bushing elements for sport collisions. Application in the analysis of head impacts in rugby contact events.

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Abstract

Introduction

Head collisions in sport can result in catastrophic cervical spine injuries [1]. Musculo-skeletal (MSK) modelling can help analyse the relationship between players' motion, external loading and internal stresses that lead to injury. However, sport specific MSK models are lacking. In automotive research, the intervertebral disk behaviour has been represented as viscoelastic bushing elements, whose parameters are often estimated in quasi-static conditions [2] that may lack validity in dynamic impacts. The aim of this study was to develop a validated cervical spine model for axial impacts and use it for the analysis of head-first rugby collisions.

Methods

A drop test rig [3] was used to replicate a sub-catastrophic axial head impact. A load of 80 N from 0.5 m was applied to the cranial aspect of a C2-C6 porcine spinal specimen mounted in the neutral position. The 3D motion of C3-C5 vertebrae (3 kHz) and the cranial axial load (1 MHz) were measured. The cervical region (C2-C6) of an existing rugby-specific MSK model [4] was scaled to the specimen before inverse kinematics was performed in OpenSim 3.3.

Forward simulations driven by the measured impact load were performed in OpenSim, and the compressive viscoelastic properties of the C3-C4 joint were optimised (Genetic Algorithm, MATLAB) to minimise tracking errors. A 6-DoF viscoelastic bushing element [2] was updated with the optimised compressive viscoelastic parameters. Elements were implemented at the C3-C4, C4-C5 and C5-C6 joints of the full-body model [4] which was used to analyse the effect of neck flexion angle on spinal loading during head-first scrum impacts through forward simulations [5].

Results

The optimisation converged to a solution of 3.8×10^6 N/m and 1360 Ns/m for compressive stiffness and damping respectively (Fig.1-a). Larger flexion angles resulted in increased compressive vertebral loading with timings of maximum compression occurring between 33-35 ms (Fig.1-b).

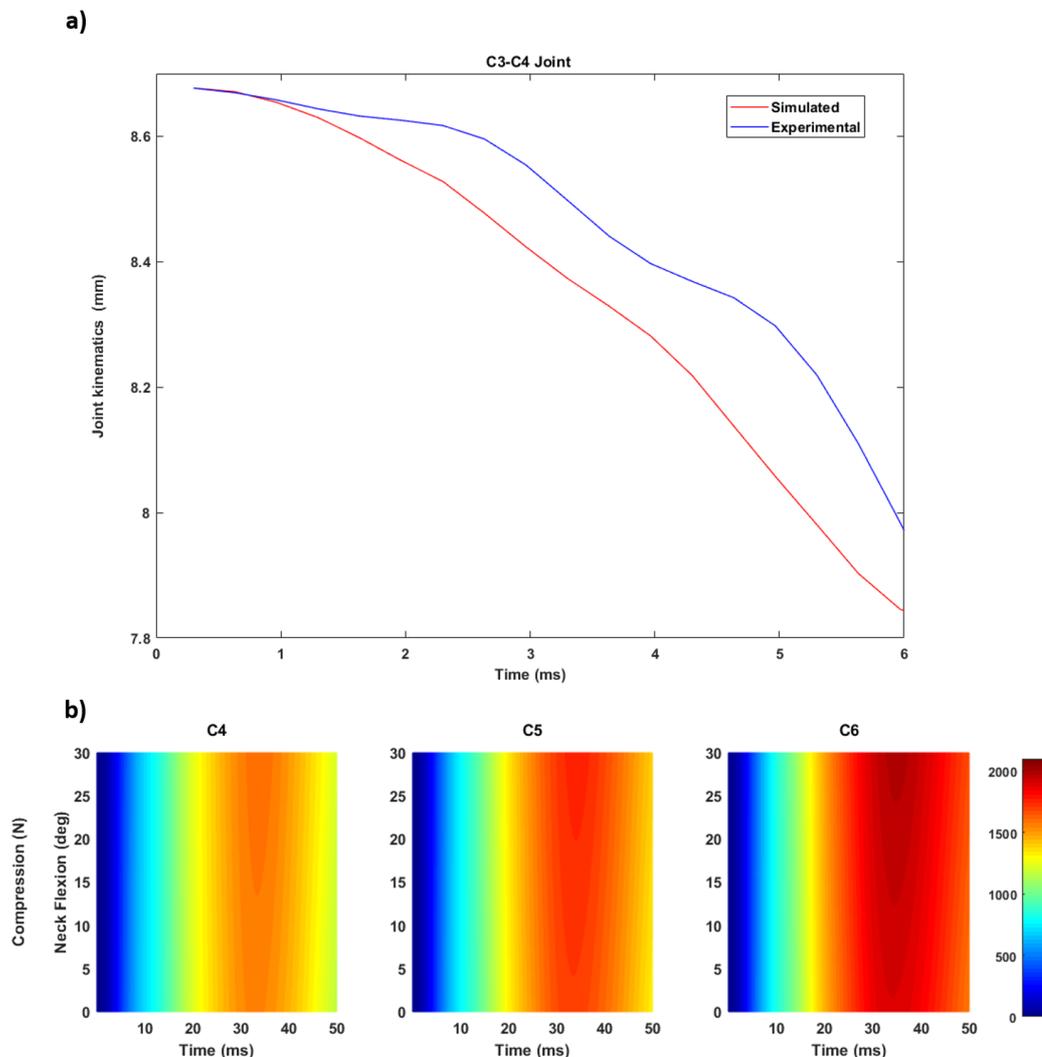


Fig. 1: Comparison of experimentally measured and simulated joint kinematics using the optimal bushing parameters under the impact load **(a)**. Compressive loads calculated from the intervertebral bushing elements as a function of neck flexion angle (y-axis) and time (x-axis) on C4, C5 and C6 vertebrae **(b)**.

Discussion

Optimal bushing parameters were of the same order of magnitude as values reported in the literature [2] with stiffness increasing significantly more than damping (153% vs 36%) compared to previous quasi-static values. Vertebral loads calculated from the bushing elements were in line with the literature [5]. These results and their implementation in injury analysis support the methodology used and are the initial step towards developing a model to accurately predict cervical spine injuries in sport.

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