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CERVICAL SPINE INJURIES IN RUGBY SCRUMMAGING: IS BUCKLING THE MOST LIKELY INJRY MECHANISM?

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INTRODUCTION

Scrummaging is related to the largest incidence rates of catastrophic cervical spine injuries in rugby union [1]. Misdirected scrum engagements are therefore associated with acute cervical spine injuries, but also repetitive impact engagements can generate functionally impairing injuries and chronic degeneration of the spine. A full understanding of the internal loading is key to implement new strategies for improving players' safety on the field and optimising rehab or training programmes for neck strengthening and mobility.
The aim of the current study was to investigate how i) neck muscle activation level, and ii) neck flexion angle affect individual vertebral loading due to misdirected rugby scrum loads.

METHODS

An integrated approach combining *in vivo*, *in vitro*, and *in silico* analyses was adopted to drive computer simulations using a musculoskeletal model. A three-player rugby union front row engaged against a scum machine combined with an instrumented anthropometric testing device (ATD) (Hybrid III, Humanetics, Germany), positioned with the head at 0º (Fig 1).

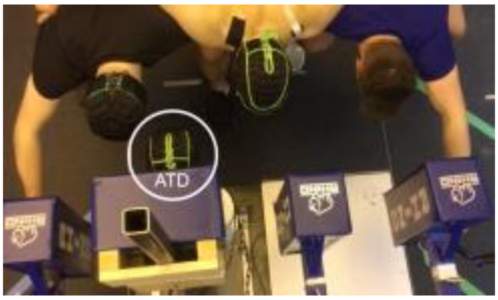

Fig 1: Experimental setup including an ATD positioned between scrum machine beams in the hooker position.

EMG signals (Delsys Trigno, Delsys Inc, USA) were collected at 2000 Hz bilaterally from the sternocleidomastoid and upper trapezius of the hooker. Scrum force and moment data were collected from the ATD at 500 Hz.
EMG and force data were used as input to the OpenSim "Rugby Model" [2] (Fig 2) to run a set of forward dynamics simulation (OpenSim 3.3, Stanford University, USA) in which both inputs (i.e. muscle activation) and initial conditions (i.e. neck angle) were programmatically varied.
In vivo flexor and extensor muscle activation patterns were linearly scaled (50 to 200%) in Matlab (R2014a, Mathworks Inc., USA) and used as controllers for the muscle model. The same extensor and flexor activation pattern was used bilaterally on the model's respective muscle groups. The neck pre-flexion value was set as simulations initial condition at 16 different angles, ranging from 0º to 30º (Fig 2).
Forces were scaled to 400% (F_{PEAK} ~ 2200 N) approximating a full scrum impact on a single player and applied to the base skull segment.

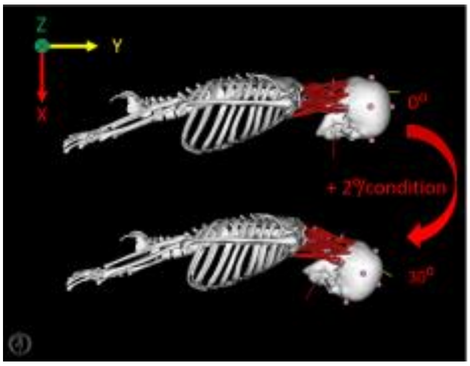

Fig 2:"The Rugby Model" and the neck pre-flexion angles used in the Forward Dynamic simulations.

Intervertebral loads were analysed at C4, C5 and C6 vertebral level through OpenSim 3.3 Joint Reaction Analyses tool.
The forward dynamic's integrator was set to a maximum step size of 10^{-4}, minimum step size of 10^{-10}, error tolerance of 10^{-8} and output precision of 25. Joint reaction analysis was performed at a step interval of 1 with all forces applied and expressed on the 'parent body'.

RESULTS AND DISCUSSION

Maximal compressive loads were observed 28-30 ms after impact, considerably earlier than peak impact force was reached (>80 ms). Peak force timings also support the argument that scrummaging injuries occur significantly earlier than cervical spine hyperflexion [3].Flexion angles greater than 20˚ resulted in a larger bimodal compression response observed in C4, C5 and C6 (Fig 3).Lower (C5-C6) and upper/mid (C4) cervical spine showed a different loading pattern in terms of shear forces, whilst the extension moments were overall comparatively small; shear forces decreased with the head flexion angle in C6 and C5, whilst C4 generally showed higher shear forces and extension moment. Such a loading pattern suggests a direct relationship between the vertebral position (e.g. upper or lower cervical spine) and injury mechanisms.

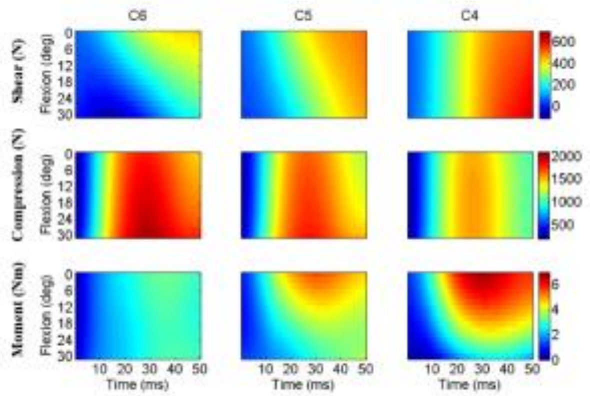

Fig 3: Cervical spine segments (C4, C5 and C6) response to impact load of 400% with muscle activation at 150% of the experimental values.

The lordotic cervical spine can dissipate the energy of the axial impact thanks to the vertebral relative motion and the contribution of the surrounding soft tissues (i.e. musculature and ligaments). Increased neck flexion causes a more axially aligned cervical spine, and a lower damping response due to its natural lordosis. Axial force placed on the head is therefore transmitted along the spine's longitudinal axis with large amounts of energy transferred directly on the vertebral structures [4]. This is evident for lower cervical spine vertebrae which are characterised by a more constrained motion than upper/mid vertebrae, and therefore subjected to higher axial loading. On the contrary C4 is more subjected to shear forces and extension moments (Fig 3 and 4).

From a clinical perspective, the predominant axial loading of the lower cervical spine, and shear/extension loading of the upper/mid spine can be logically related to the most common C4 dislocation and C5/C6 compression/burst rugby scrum injuries [5].

Active muscular force had a significant effect on the dynamic response of the cervical spine; higher muscle activations increased cervical spine compressive load and extension moment. Previous studies [3] showed that during simulated axial head impacts muscle preload increased the critical buckling force by aiding the structural stability of the segment. Their results indicated that increasing the level of co-contraction in the pre-engagement phase has the potential to shield from injury. However, our results showed a dual scenario: i) muscular pre-activation and higher levels of stiffening generates greater compressive forces potentially predisposing to injury, but ii) they can also decease the shear load at lower vertebral level (C6 and C5) (Fig 4).

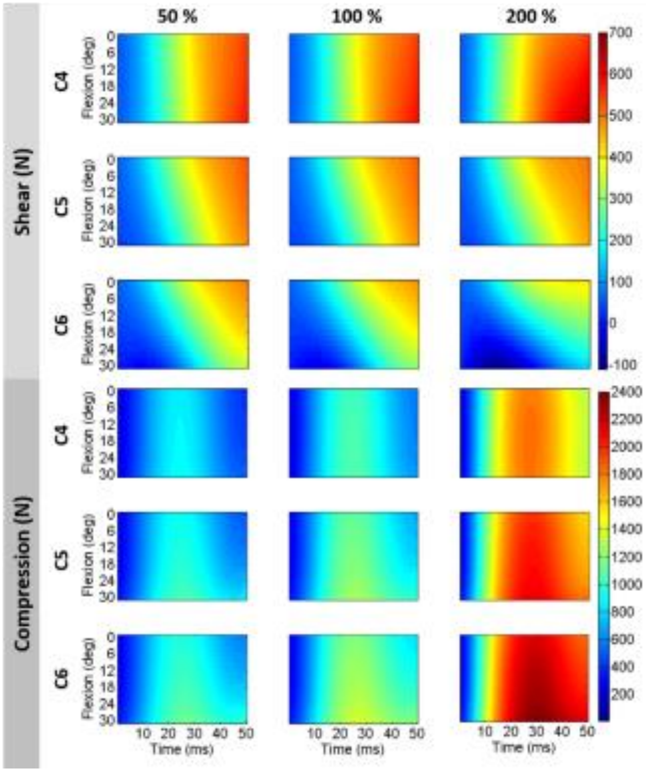

Fig 4: Cervical spine segments (C4, C5 and C6) shear and compression response to impact load of 400% with muscle activation at 50, 100 and 200% of the experimental value. For 200% (A_{ext}=1.04 and A_{fle}=0.56).

CONCLUSIONS

Simulations showed axial loading responses of the cervical spine that support buckling as the most likely injury mechanism in misdirected scum scenarios. The neck muscles activation and vertebral level can alter the impact energy response of the cervical spine.

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