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Evaluating Accident Reconstruction Method for Mountain biking Spinal Injuries: From Accident Data to Biomechanical Modeling of the Injury Mechanism

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1. Introduction

Mountain biking (MTB) is growing in popularity but carries a high injury risk, with 16.8 injuries per 1,000 hours of practice (Carmont, 2008). Although spinal injuries are relatively rare, they account for 30–40% of severe trauma cases (Kim et al., 2006) and often result from over-the-handlebars (OTB) falls (Dodwell et al., 2010). Despite their severity, the specific back impact conditions—such as impact area, velocity components, and loading patterns—leading to thoracolumbar fractures remain poorly understood. Bridging this knowledge gap is essential for improving MTB rider safety, particularly by informing the development and evaluation of protective back equipment. Combining video analysis, epidemiology, MTB simulation, and finite element (FE) simulation has been successfully used to understand injury mechanisms in traffic accidents. We aimed to evaluate whether this approach could also be effective in understanding spinal injury mechanisms in mountain bike (MTB) accidents. The objective of this work is to develop a methodology and to evaluate its ability to reproduce real injury cases.

2. Methods

2.1 Accident Data Collection

Two complementary datasets were analyzed using a standardized questionnaire to collect injury details and crash circumstances.

1. **Video Dataset**: 534 crash videos were collected from the social media platform Pinkbike, all involving traumatic injuries. Among them, 25 cases with confirmed spinal injury were identified.
2. **Clinical Dataset**: Hospital records from CHU Grenoble documented 74 severe MTB crashes with 11 spinal injury cases.

Both datasets analysis offered a more comprehensive understanding of the crash scenarios and injury mechanisms associated with thoracolumbar spinal trauma.

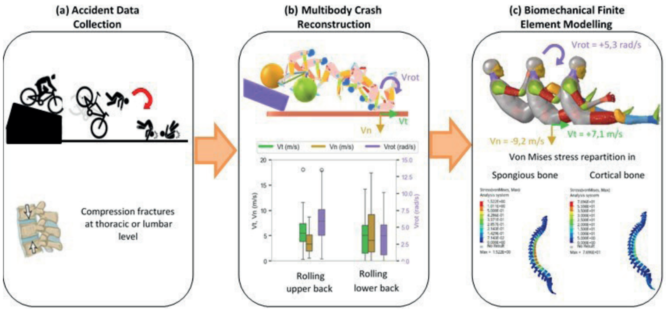

Figure 1. (a) Identification of the main scenario leading to thoracolumbar injury **(b)** Impact conditions of the back using multibody simulation **(c)** Injury Mechanism using Biomechanical Modelling.

Credit : Sophie Bonte.

2.2 Multibody Crash Reconstruction

A multibody model of a MTB forward falls was developed using a Human Facet Model (figure 1b) and used to reconstruct 288 falls with various speeds, slopes, bike inclinations, handlebar forces, and fall heights. Back

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impact conditions that may lead to thoracolumbar injuries were analyzed, focusing on impact area, angle, and velocities (normal, tangential, and rotational).

2.3 Biomechanical Finite Element Modelling

Representative severe back impact conditions (at the 3rd quartile for Vn, Vt, and Vrot) were used to simulate spinal loading using the THUMS V4 human FE model. The vertebral strain distributions and flexion moments were analyzed to identify risk of injury (compression fractures, flexion, or torsional failure modes).

The capability of the entire methodology to reproduce the correct injury mechanism was evaluated by comparing the injury predicted by the FE model to the injury patterns observed in real cases.

3. Results and discussion

3.1 Scenarios Leading to Thoracolumbar Injuries

Forward fall, over-the-handlebars were the leading cause of spinal injuries (81%), mostly after poor jump landings (64%). Thoracolumbar injuries primarily resulted from rolling impacts (70%), either head-first then back (36%) or overflip back impacts (34%). One type of vertebral fractures was mainly observed compression fractures in the thoracic (T6-T12) and lumbar (L1-L3) regions.

3.2 Back impact conditions in realistic crashes

Among all simulations, 58.3% resulted in an over-the-bars crash, with rolling impacts in 57% of cases. Among these crashes, we distinguished upper back impact first from lower back or rear pelvis. Severe back impacts (Q3 values) had normal velocities of 5–9 m/s, tangential 7–7.5 m/s, and rotational 5–7.5 rad/s, varying by scenario and impact area. A key factor was the significant rotational component in impact speed and angle.

3.3 Finite Element Simulations of Injury Mechanisms

To confirm that the impact conditions obtained in 3.2, could produce the injury observed in 3.1 we reproduced one impact corresponding to the third quartile of 3.2 results (Vt: 7.3m/s; Vn: -9.2 m/s; Vrot: 5.3 rad/s). The combination of rotational, tangential and normal impact velocities resulted in significant compression loading in the vertebral body of the thoracolumbar spine of the FE model.

The computed loading and predicted injury by the FE model correspond well with the main type of vertebral fracture observed in 3.1: compression fracture of the vertebral body suggesting that the methodology is relevant to this type of crash.

4. Conclusion

The proposed multidisciplinary methodology, was able to identified and replicate a biomechanical injury signature associated with thoracolumbar spinal trauma in MTB : a compression fracture of the vertebral body provoked by an other the bar crash scenario.

By quantitatively characterizing these conditions and confirming their effects through FE modeling, the study lays the groundwork for more relevant protective gear testing protocols. The initial findings suggest that future protective equipment should be evaluated under multi-axial dynamic conditions to account for the complex impact profiles observed in MTB crashes.

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Conflict of Interest Statement

Arsène Thouzé and Sophie Bonte are employed by the company Decathlon, which manufacture bikes and protective equipment.

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