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Numerical Evaluation of a Back Protector During a Typical Snowboarding Backward Fall

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1. Introduction

Snowboarding carries a high risk of severe spinal injury during falls : spinal injuries account for 30 to 45% of severe injuries (Injury Severity Score (ISS)>15) on ski slopes potentially leading to neurological damages (Bigdon et al., 2019). Back protector (BP) devices are used to mitigate these risks, and must be properly evaluated to assess their effectiveness. However, their efficiency in reducing spinal loading and preventing spinal injury during a winter sports fall has not yet been evaluated.

Previous studies, based on epidemiological and accidental studies, have identified the snowboarding backward falls as typical scenarios leading to vertebral fractures. Multibody accident reconstruction (Wei et al., 2019) and finite element (FE) analysis of the spinal injury mechanism (Wei et al., 2023) enabled to refine the impact conditions and injury mechanisms. In one critical scenario, the snowboarder impacts the lower back at a high normal speed (2.4 m/s) and with a significant rotational speed (6.0 rad/s).

This study aims to evaluate a commercial winter sports BP (Decathlon DBCK 500) and its ability to reduce spinal injuries in this snowboarding backward fall scenario. To do so, the BP was characterized, modeled and incorporated into a FE reconstruction of the crash scenario, and its effect on spinal loading was evaluated by comparing simulations with and without the protector.

2. Methods

2.1 Modeling of the back protector

The BP, fully composed of a 16 mm thick foam, was characterized by extracting foam samples (40×40×12.5 mm) then subjected to uni-axial compression at speeds of 0.01, 0.10, 1.00, and 2.00 m.s^{-1} using a servo-hydraulic system. Drop tower tests were conducted as well, from 4 heights ranging from 0.35 to 0.80 m with a 7.14 kg flat mass impacting the whole foam surface. FE modeling replicated these tests, representing the foam as Fu-Chang material with rate-sensitive behavior, with stress-strain curves adjusted to fit experimental force-time histories. The BP model, incorporating these calibrated properties, was validated through drop tests from 0.6 m and 1.5 m on three impact zones with a rectangular-shaped impactor (Fig. 1.a). Each drop test was performed twice to ensure repeatability.

2.3 Human Body Model (HBM)

A FE virtual HBM (THUMS V5.03, using LS-DYNA R13.0) previously validated for impact on the back (Wei et al., 2023) was used for this study.

A preliminary independent simulation was performed to fit the validated BP to the geometry of the back of the HBM (Fig. 1.b): gravity was applied to the HBM to make it fall over the BP, the latter being deformed according to the geometry of the HBM's back. A high friction coefficient ($\mu = 5$) was then set between the

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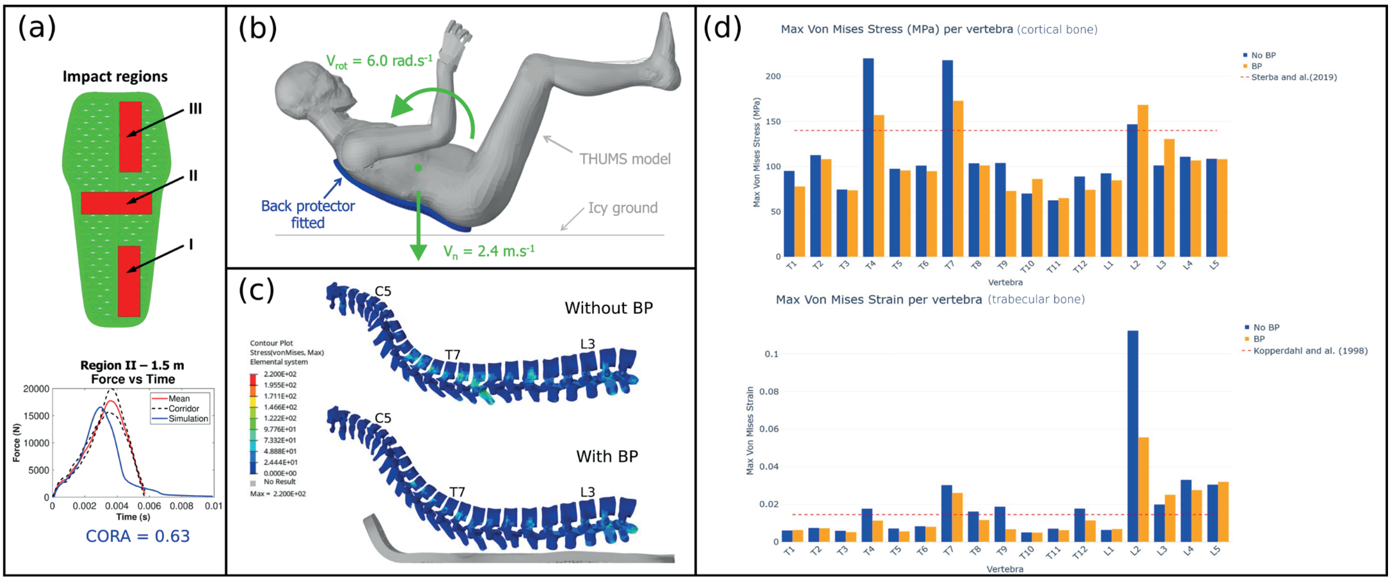

Figure 1: (a) FE model of the BP validated for drop tests, matching experimental data. **(b)** Fitting of the BP and simulation initial velocities. **(c)** Representation of VM stress in the cortical bones without (top) and with BP (bottom). **(d)** Maximum VM stress and strain in cortical (top) and trabecular bones (bottom). Fracture thresholds are shown as dotted lines.

BP and the back of the body to ensure an adequate contact at impact.

2.3 Modeling of the crash scenario

The HBM was positioned above a rigid surface representing an icy ground, and was projected with a normal velocity (V_n) of 2.4 m.s^{-1} and rotational velocity (V_{rot}) of 6 rad.s^{-1} (Fig. 1.b). Given the low coefficient of friction and the absence of tangential velocity, contact was considered frictionless. The risk of vertebral fracture was evaluated in the cortical bones using the Von Mises (VM) stress, and in the trabecular bones using the VM strain, with fracture thresholds of respectively 130 MPa (Sterba et al., 2019) and 0.0145 (Kopperdahl & Keaveny, 1998). Simulations with and without BP were performed to evaluate the effect of the back protector on the risk of vertebral fracture.

3. Results and discussion

The mechanical response of the BP model satisfactorily matched the impact force time-histories observed in the 6 configurations of experimental drop tests (Fig. 1.a): CORrelation Analysis scores (software CORA 3.6) ranged between 0.61 and 0.69.

During the crash (Fig. 1.c), high stresses were recorded in the spinous processes of the HBM vertebrae in the T7–T9 and L3–L5 segments due to the direct impact with the ground. These are typical indicators of spinous process fractures previously described in some snow sport crashes (Wei et al., 2023). Additionally, high stresses were observed in the vertebral bodies away from the impact zone (C5–T7 segment), suggesting a propagation of compressive force along the vertebrae after the impact. These localized stresses are significant indicators of compressive fractures, which are predominantly observed in snow-sport crashes.They were observed with and without BP. However, the use of the BP reduced the maximum stresses and strains in 79% of the cortical and trabecular bones (Fig. 1.d). In particular, 4 trabecular bone strains fell below the fracture threshold with the BP; in the cortical bone stresses, the most impacted vertebra (T4) exceeded the injury threshold by 57% without the BP, while by only 12% with the BP. This suggests that the BP reduces both the risk and severity of injury, although it does not completely prevent it because some vertebrae still surpass the thresholds.

4. Conclusions

The study demonstrates that the simulated BP effectively reduced impact loadings and mitigated injuries to the spine during these falls, justifying its use. The study clearly identified two injury mechanisms consistent with those reported in snow sport epidemiological studies:

direct impact to the spinous processes and propagation of compressive force along the vertebral bodies. Both mechanisms were reduced by the use of the BP.

The study also shows that the protection provided by the BP has limitations, as some of the load in the spine still surpassed the injury threshold. This first evaluation was performed on only one realistic crash scenario, and further study modeling multiple scenarios with a similar method will be necessary to build a complete evaluation of the device.

Conflict of Interest Statement

Sophie Bonte and Simon Duraffourg are employed by the company Decathlon, which manufactures snowboards and protective equipment, such as the back protector studied here.

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