An instrumented surrogate for characterizing hockey puck impacts to the foot and ankle for safer skate boot designs

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Introduction: High-speed pucks pose a serious injury risk to ice hockey players during gameplay. Protective gear can attenuate some puck impact force, but injury prevention standards generally focus on head and neck gear. As such, modern skates are designed for performance (reducing mass and improving mobility) over safety. Given that foot and ankle injuries are common in hockey and puck blows are the primary cause of fractures and contusions to the region [1], there exists a critical need to investigate the protective features of current skate boot designs.

Objective: The objective of this research was to quantify puck load attenuation provided by modern hockey skate boots using a novel instrumented foot and ankle surrogate.

Methodology: A custom foot and ankle surrogate was designed using anatomical measurements scaled to accommodate a senior size 8 regular fit skate boot. The surrogate was fabricated with a 3D-printed plastic 'hard tissue' core and a removable urethane 'soft tissue' covering. Six locations on the medial, lateral, and anterior aspects of the foot and ankle vulnerable to puck impact injuries were identified from clinical literature, and FlexiForce sensors (Tekscan, Norwood, MA) were adhered to the hard tissue core at these locations to measure bony loading through skate padding and soft tissue coverage.

Compression testing was performed on an entry-level skate (Bauer Vapor Volt 2.0) and an elite-level skate (True Catalyst 9). The skate locations chosen were the quarter package and tongue, corresponding anatomically to the medial malleolus and talus. The instrumented surrogate was inserted into each skate, and a material testing machine with a hockey puck loading cap applied a ramp load of 1000 N at 0.1 mm/s to the skate and surrogate assembly. Three trials per loading location were conducted for each skate.

Results: The surrogate proved highly repeatable, with coefficients of variation for the repeated tests <3%. The elite-level skate attenuated more force than the entry-level skate at both locations. At the tongue, the forces measured at the surrogate 'hard tissue' were 612.3 ± 11.6 N (39% attenuation) and 800.0 ± 8.1 N (20% attenuation) for the elite- and entry-level skates, respectively. Force was further attenuated at the quarter package, with measured loads of 330.3 ± 6.9 N (67% attenuation, elite-level) and 737.6 ± 10.1 N (26% attenuation, entry-level). Measured loads on the surrogate were consistent with known features of skate construction; the quarter package of a given skate is stiffer than the tongue, and elite-level skates are stiffer than entry-level models.

Conclusions: To date, no known surrogate exists to evaluate the protective characteristics of hockey skates. A novel surrogate was designed in this work to investigate the protectiveness of entry- and elite-level skates, and stiffer skate features generally provided superior load attenuation. Ongoing testing involves performing a suite of dynamic impacts under realistic puck loading conditions. Continued use of the surrogate will evaluate the protective features of elite-level skates to inform new design recommendations and standards rooted in injury prevention.

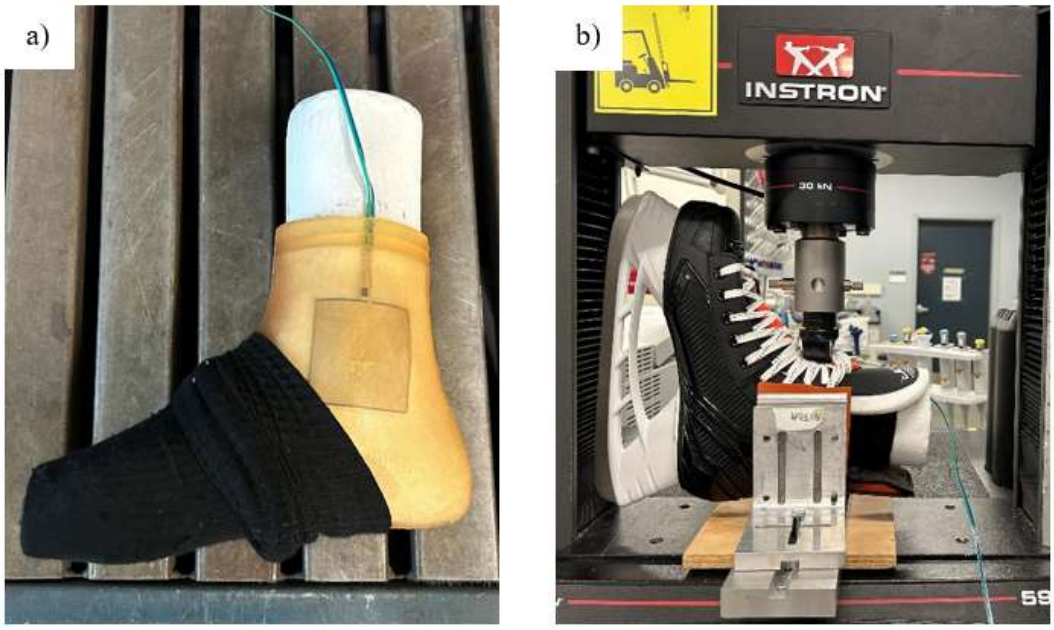

Figure 1. (a) Novel foot and ankle surrogate showing medial malleolus instrumentation, and (b) experimental setup for tongue testing on the entry-level skate.

References:

[1] J. C. Baker, E. G. Hoover, T. J. Hillen, M. V. Smith, R. W. Wright, and D. A. Rubin, "Subradiographic Foot and Ankle Fractures and Bone Contusions Detected by MRI in Elite Ice Hockey Players," *Am. J. Sports Med.*, vol. 44, no. 5, pp. 1317–1323, May 2016, doi: 10.1177/0363546515626181.