Puck Impacts to Hockey Skates Evaluated via a Novel Instrumented Surrogate

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I. INTRODUCTION

Ice hockey gameplay is fast-paced with considerable injury potential. Shot speeds can exceed 160 km/h in the National Hockey League [1], where puck impacts are responsible for up to 14% of all injuries [2]. Impact safety standards have been established for some hockey gear (*e.g.* helmets), but no such protocols exist for skates, and modern boot designs are primarily performance-driven with limited padding [1]. Previous work examining foot and ankle trauma in elite-level hockey players revealed that puck contact was responsible for the majority (63%) of all reported fractures and severe contusions, and that these injuries were primarily to medial foot and ankle bones of defensemen as they intercepted shots [1]. The purpose of the present research was to investigate hockey skate boot protectiveness, which has yet to be quantified in available literature despite the prevalence of puck impact injuries. The second objective was to develop a novel instrumented surrogate necessary for measuring puck loads transmitted to foot and ankle bones through skate boots.

II. METHODS

A generic skate last served as the basis for the surrogate geometry and was manually scaled to meet foot and ankle proportions expected for a size eight, regular-fit senior boot. The surrogate was divided into a removable 'soft tissue' covering, cast from urethane rubber and varying in thickness from 3 mm to 8 mm (per CT scan measurements), and a plastic 'hard tissue' core. FlexiForce A401 sensors (Tekscan, Inc.) were calibrated to correlate analogue sensor outputs with impact forces. A linear impacting apparatus was used to apply dynamic loads up to 10 kN, and voltage–force data were fitted with third-order polynomial curves to generate a unique calibration equation for each sensor. Sensors were adhered to the 'hard tissue' at six locations deemed vulnerable to puck impact injuries (the medial and lateral malleoli, first and fifth metatarsals, navicular, and talus) to measure forces transmitted to these bones through the overlaying compliant 'soft tissue' (Fig. 1(a)).

Three samples each of three elite-level skate models from separate manufacturers (anonymised as Skates A, B and C) were selected for impact testing, and skate masses and prices were recorded. The surrogate was inserted into each skate, and a custom fixture was fabricated to rigidly support the skate with each vulnerable location normal to the exit of the impacting apparatus. Impacts were performed at 11 m/s using a custom projectile (665 g) fitted with a hockey puck impact cap to target an energy of 40 J (Fig. 1(b)), representing an 80 km/h shot. All six locations on each skate sample were impacted five times each, with five minutes between consecutive impacts to allow for skate padding recovery. One-way analyses of variance with Tukey post-hoc tests were performed to identify differences among force outcomes at each location for the tested skate models.

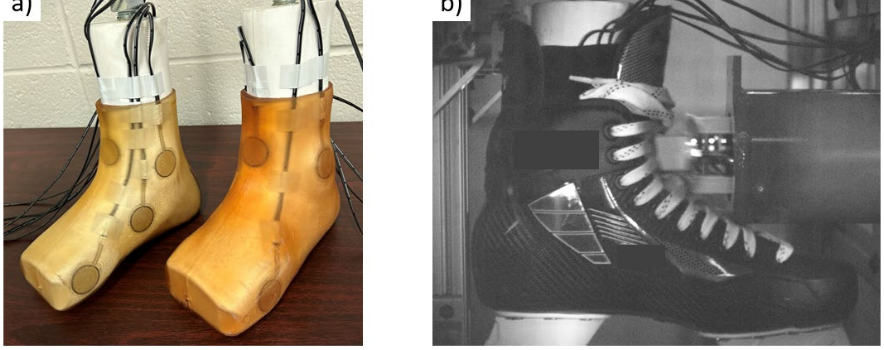

Fig. 1. (a) Left- and right-side instrumented surrogates; (b) a skate positioned for impact testing at the talus.

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III. INITIAL FINDINGS

The mean coefficient of determination for fitted third-order calibration curves was 0.997 ± 0.002, and the root mean square errors normalised to percentages of the maximum calibration loads averaged 1.4 ± 0.6% across all sensors (n=12). Tested skates ranged from $800 to $1300 CAD per pair; Skate B was the heaviest and costliest, while Skate C was the lightest and lowest cost. The average energy of the skate impacts was 40.2 ± 2.3 J (n=216). Mean impact forces across the three skate models and six locations ranged from 2.2 kN to 5.2 kN and tended to be highest at the malleoli and metatarsals, whereas impact durations ranged from 1.5 ms to 3.3 ms and were always longest for talar impacts (Fig. 2(a)). When directly comparing skate models, Skate C most effectively minimised loads from impacts to the sides of the boot, while Skate A best attenuated impacts to the boot tongue at the talus (Fig. 2(b)).

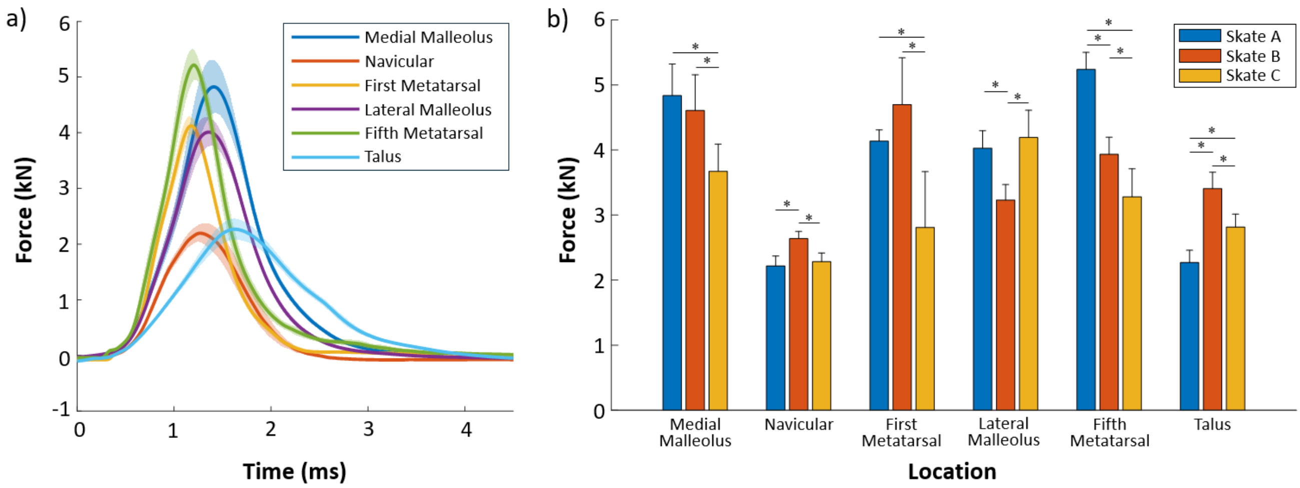

Fig. 2. (a) Mean force-time traces for impacts to Skate A (solid lines), with ±1 standard deviation shown as shaded bands; (b) mean and standard deviation force data for all skate models, where asterisks indicate statistically different pairings for a significance level of 0.05.

IV. DISCUSSION

This work represents the first known investigation into the puck impact protection provided by hockey skate boots, as well as the first known foot and ankle surrogate developed for exploring this injury mechanism. Given that typical human surrogates (e.*g.* anthropomorphic test devices) lack anatomical detail and instrumentation in the feet, this new surrogate represents a valuable contribution to the injury biomechanics field. The ‘soft tissue’ material was selected to match the compliance of human tissue, important for accurately evaluating protective systems, and the use of highly correlated sensor calibration data contributed to a reliable force measurement system.

No known injury limits exist for the bones and impact conditions targeted in this work, and as such it is difficult to conclude whether the tested skates could adequately protect the foot and ankle against puck impact injuries; however, the most vulnerable case would have been Skate A at the fifth metatarsal. Notably, protective performance did not necessarily improve with skate mass and cost, as the lightest and least expensive model (Skate C) minimised transmitted loads at more locations than its counterparts. Next steps for this work would involve establishing injury tolerances for the relevant foot and ankle bones, as well as further varying impact conditions (for example, energies or skate models) to make experimental findings more applicable to a wider range of hockey players. Overall, this work provides a foundation for new skate testing standards rooted in injury prevention, which can ultimately improve the well-being of athletes and the safety of the sport for lasting enjoyment.

V. REFERENCES

[1] Baker, J. C., *et al.*, *Am J Sports Med*, 2016.

[2] McKay, C. D., *et al.*, *Br J Sports Med*, 2014.