# An Instrumented Surrogate for Characterizing Hockey Puck Impacts to the Foot and Ankle for Safer Skate Boot Designs


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## INTRODUCTION

- Ice hockey pucks are fast-moving projectiles that pose a substantial injury risk to hockey players
- Puck contact is the primary mechanism of severe foot and ankle injuries such as contusions and fractures [1]
- No safety standards exist for skates, and padding is often minimized to favour performance over protectiveness [2]

## OBJECTIVE

Design a novel instrumented foot and ankle surrogate and demonstrate its ability to quantify load attenuation provided by hockey skate boots.

## METHODS

### *Foot and Ankle Surrogate*

- Anatomical measurements scaled to a size 8 skate boot were used to generate a 'hard tissue' core and 'soft tissue' covering (Fig. 1a)
- The core was 3D printed with PETG, and the covering was cast with urethane rubber of 3 - 8 mm thickness (Fig. 1b)
- Force sensing resistors were mounted to multiple injury-prone locations to quantify bony loading (Fig. 1c)

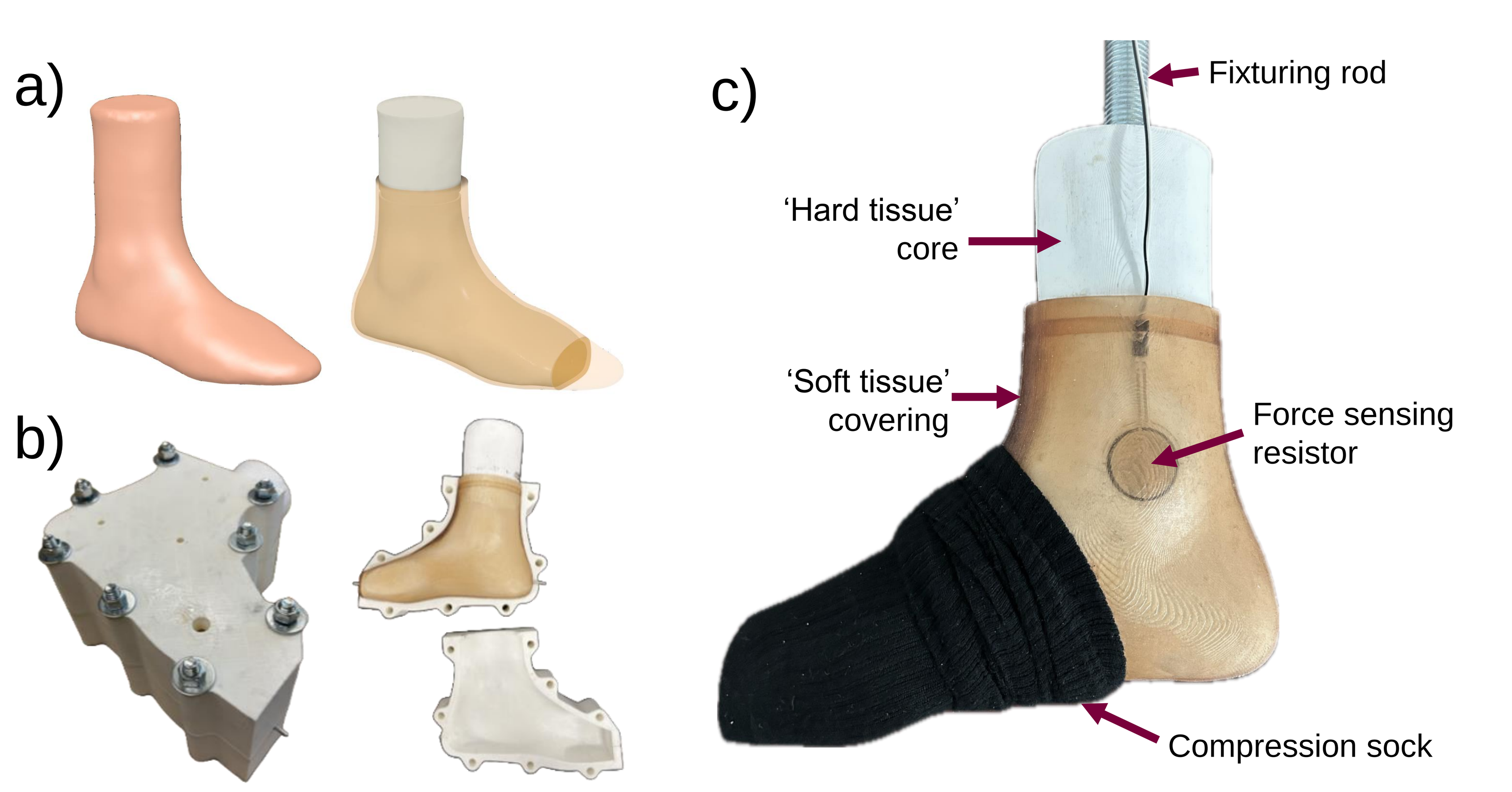


**Fig. 1 (a)** Surrogate CAD models with tissue components, **(b)** 'soft tissue' rubber casting, and **(c)** final surrogate with instrumentation at the medial malleolar injury-prone location.

### *Puck Loading*

- Evaluated protection provided by the tongue and medial quarter package (MQP) of elite- and entry-level skates

Quasi-static:

- 1 kN ramp load applied at 0.1 mm/s via a material testing machine (Fig. 2a); three repetitions per condition

Dynamic:

- 35 J impacts (≈46 mph puck shot) performed using a pneumatic impactor (Fig. 2b); five repetitions per condition

## METHODS

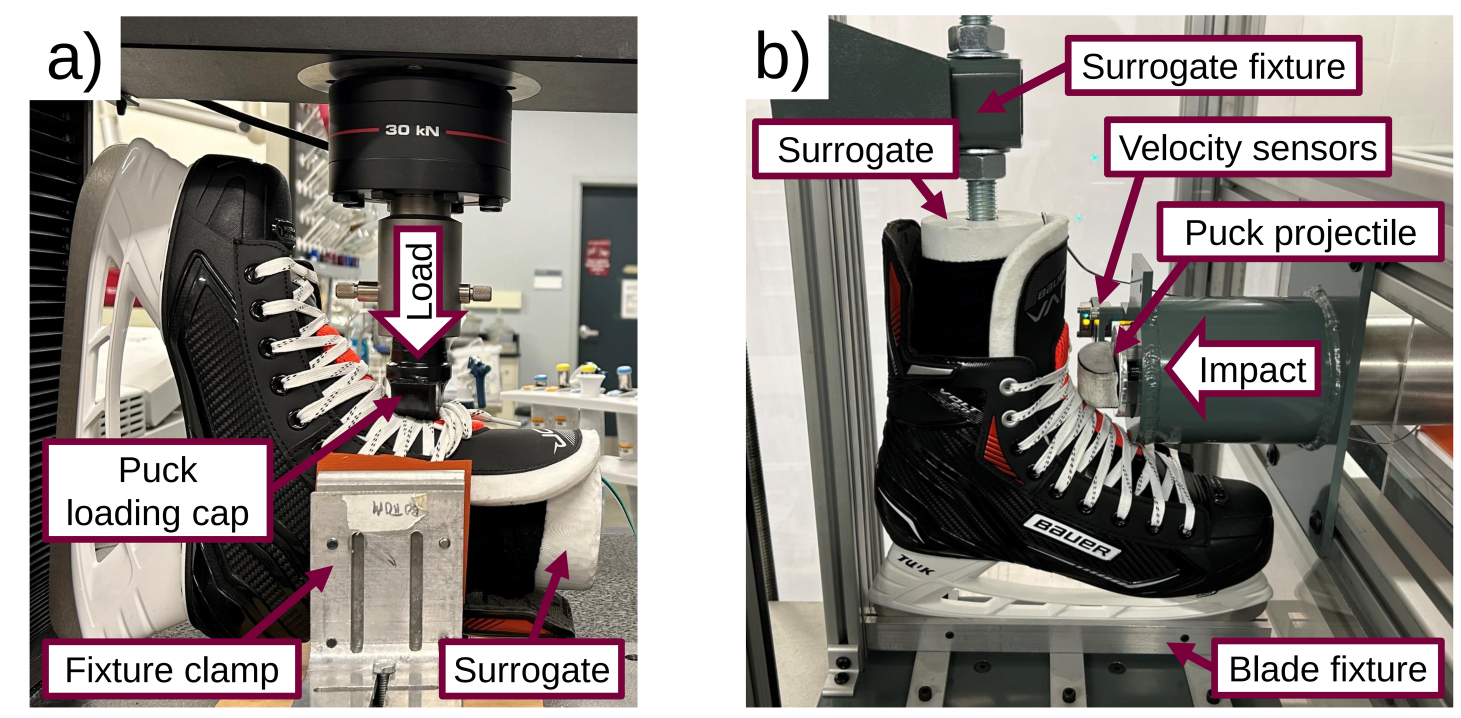


**Fig. 2** Skate tongue puck loading setup for **(a)** quasi-static testing using a material testing machine and **(b)** dynamic impact testing using a pneumatic impacting apparatus.

## RESULTS

- The surrogate proved repeatable for quasi-static tests (CV = 1 - 2%) and dynamic tests (CV = 6 - 10%)
- The elite-level skate MQP and tongue provided the most load attenuation for quasi-static and dynamic conditions, respectively (Fig. 3a)
- Tongue padding led to longer impact durations and lower peak forces under dynamic conditions (Fig. 3b)

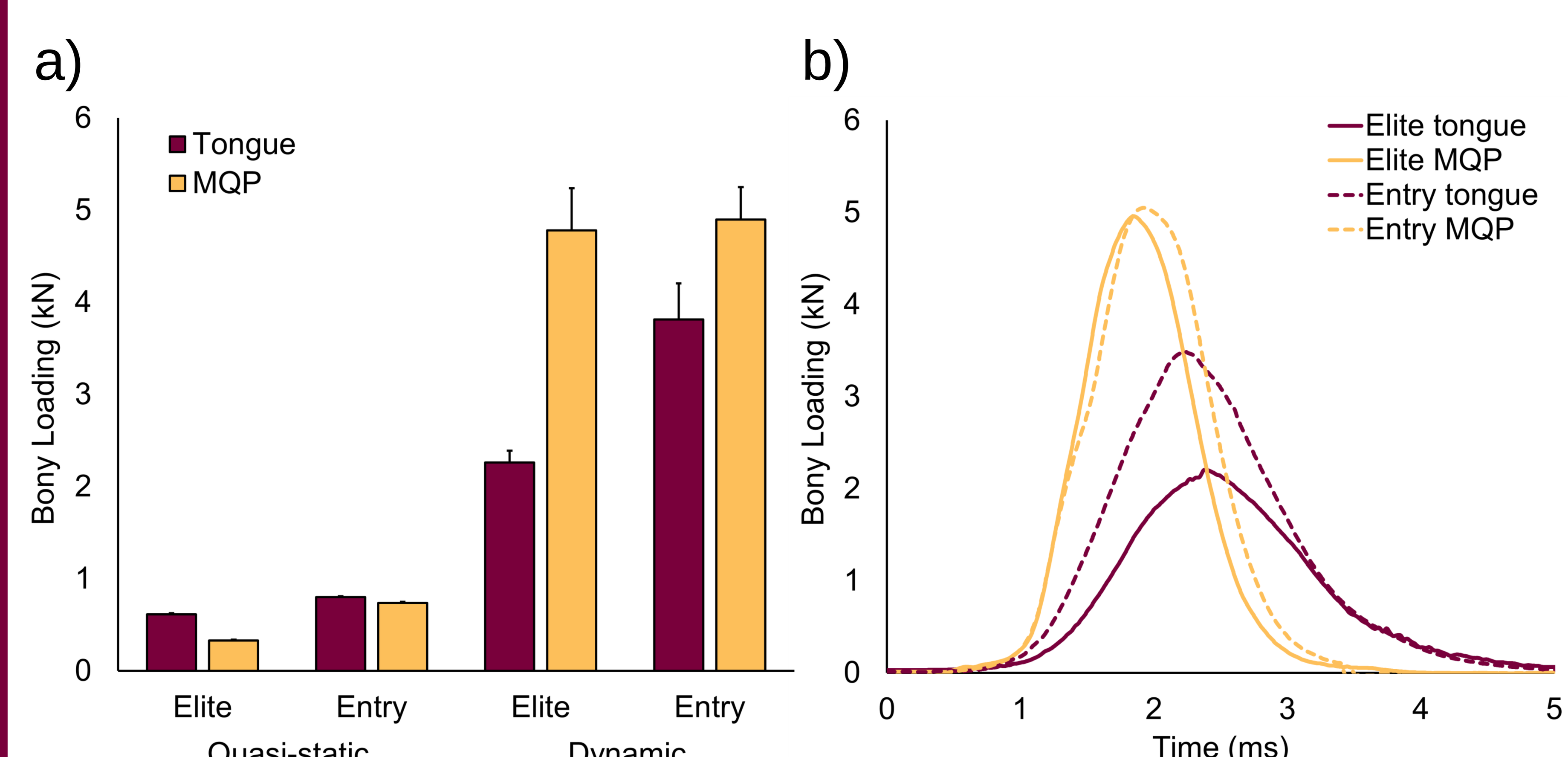


**Fig. 3 (a)** Bony loading at the tongue and MQP for elite- and entry-level skates under quasi-static and dynamic loading, and **(b)** load-time response for dynamic impacts to the tongue and MQP of elite- and entry-level skates.

## CONCLUSIONS

- The elite-level skate was most protective, although its best performing features depended on the loading rate
- Future tests will investigate the safety of multiple elite-level skate models at varying impact energies for additional injury-prone locations
- Results will inform new skate design recommendations and standards rooted in injury prevention

## 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.

[2] J. Agel and E. J. Harvey, "A 7-year review of men's and women's ice hockey injuries in the NCAA," *Canadian Journal of Surgery*, vol. 53, no. 5, pp. 319–323, Oct. 2010.





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