A Preliminary Step Towards a Calvarium Surrogate Model to Simulate Fracture

K. Adanty[a,b], K. B. Bhagavathula[b], K. N. Rabey[c,d], M. R. Doschak[e], S. Adeeb[f], J. D. Hogan[b], S. Ouellet[g], D. L. Romanyk[b,h], C.R. Dennison[a,b,i].

a. The Biomedical Instrumentation Laboratory, Department of Mechanical Engineering, University of Alberta b. Department of Mechanical Engineering, University of Alberta c. Department of Surgery, Division of Anatomy, University of Alberta d. Department of Anthropology, Faculty of Arts, University of Alberta e. Faculty of Pharmacy and Pharmaceutical Sciences, University of Alberta f. Department of Civil and Environmental Engineering, University of Alberta g. Defence Research and Development Canada h. School of Dentistry, University of Alberta i. Department of Mechanical Engineering, University of Victoria

1. Introduction

- Surrogate head models are composed of rigid-based material to achieve repeatable head-kinematic and brain responses [1-2].
- These models are effective for helmet assessment and quantifying injurious scenarios but cannot mimic a skull fracture.
- Skull fractures are life-threatening and are observed in contact sports, physical assaults, and vehicle accidents [3]. Thus, we must work towards the development of surrogates of the skull to model fracture.
- Validated skull models can be integrated with existing head forms to mimic and observe fractures and then assess strategies to prevent skull fractures.

2. Objectives

- Introduce the preliminary design of a layered beam calvarium surrogate to model fracture.
- The surrogate's stress and strain measurements at fracture were then compared against human calvarium in quasi-static 4-point bending.

3. Methods

3.1 Fabrication

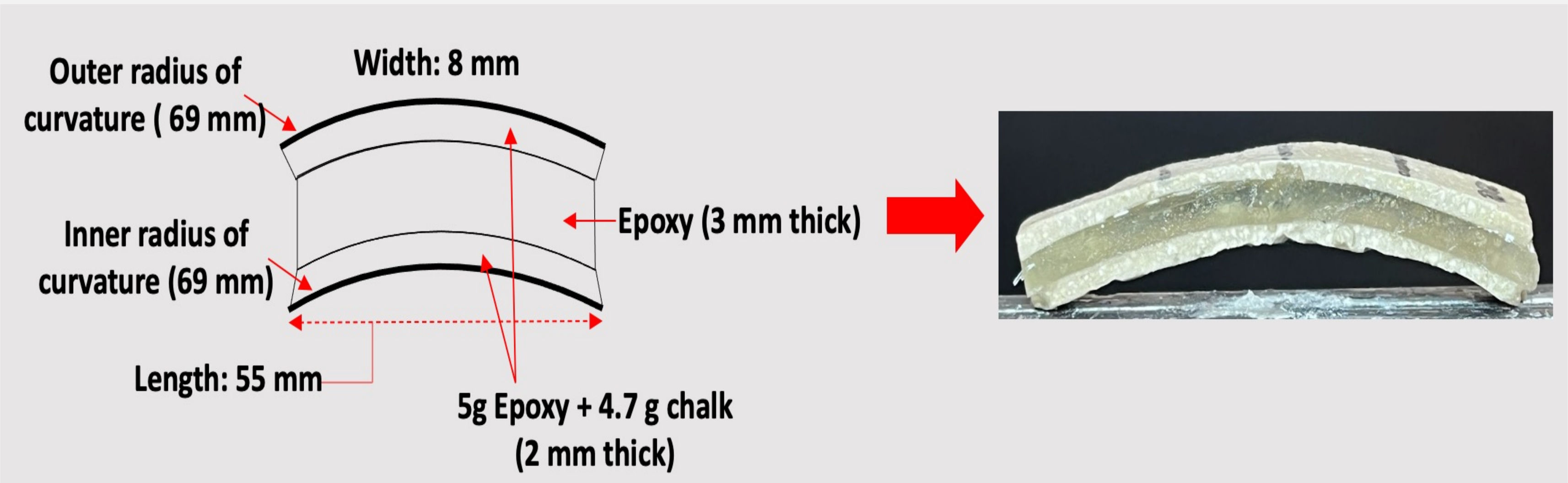

Figure 1. **A schematic (left) and photo image (right) of the surrogate model.**

- Lepage Speed Set Epoxy and powdered chalk were used to fabricate the surrogate (Fig 1).
- Epoxy and chalk were chosen to form rigidity and to induce brittleness in the surrogate, respectively.
- Each layer (3) of the surrogate was fabricated and cured separately for 10 minutes in a silicone mold.
- The layers were then glued together using epoxy and cured for two weeks at room temperature (20–22 °C or 68–72 °F) prior to mechanical experiments.

3.2 Mechanical Experiments

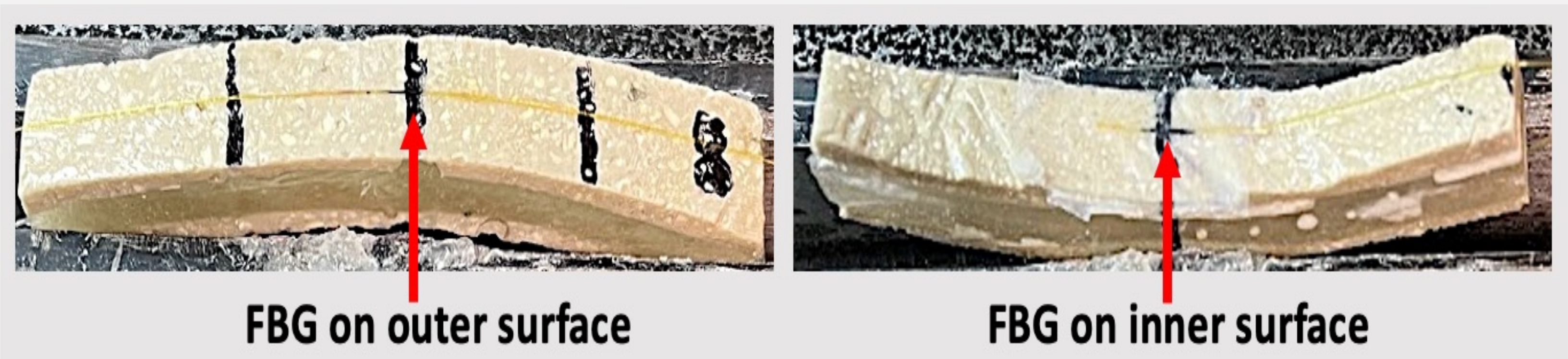

Figure 2. **Optical FBGs on the outer and inner surfaces of the surrogate model.**

- Each surrogate (n=5) was bonded with optical fibre Bragg gratings (FBGs) to quantify surface strains (%) (Fig 2).

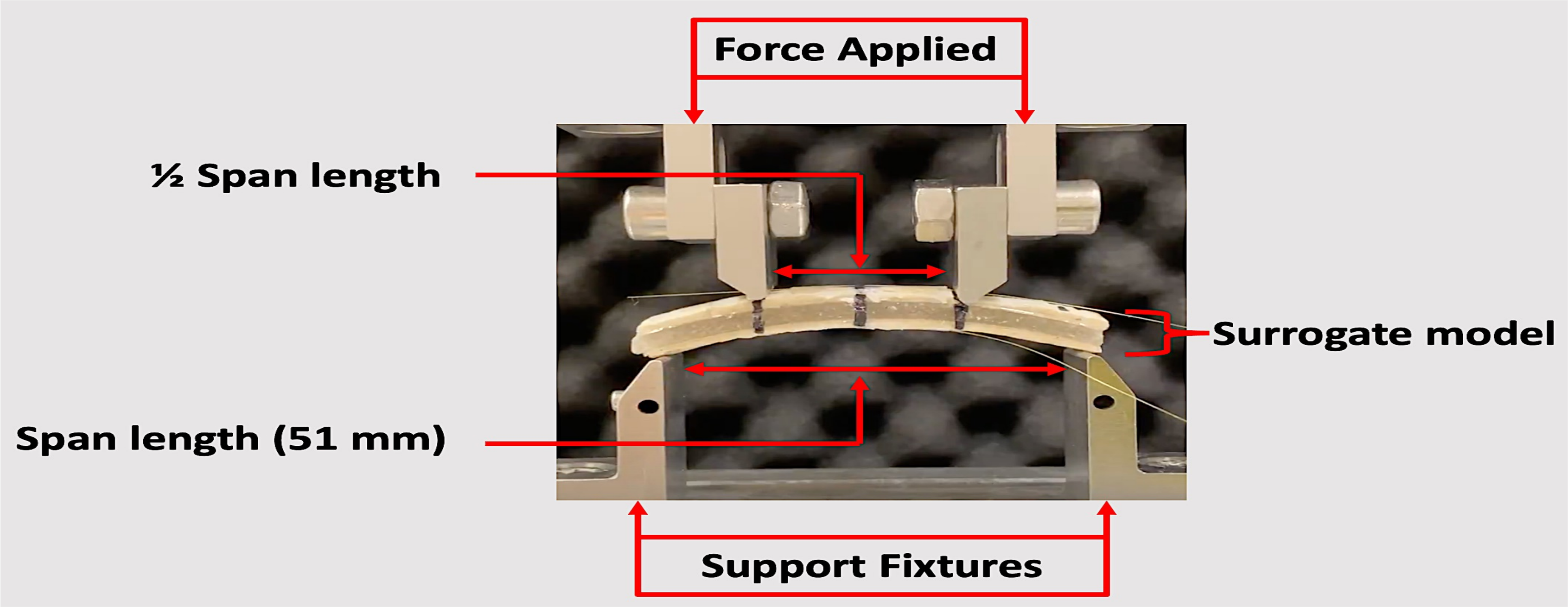

Figure 3. **The four-point bending of a surrogate model in an Instron E300**

- The surrogates underwent quasi-static 4-point bending (Fig 3) at a displacement rate of 2 mm/min until surrogate fracture.
- Stress was computed using the Euler-Bernoulli beam theorem.
- Stress and strain at fracture were compared between the surrogates and human calvaria (n=5).

4. Results and Discussion

- The average stress and strain at fracture of the surrogate model are close to one SD of the calvarias' mean (Fig 4).
- The surrogates fractured in a brittle manner as observed for calvaria.
- The flexural strength of skull simulants made of fibre-filled (210 MPa) and construction-based (60 MPa) epoxy was reported [4] but greater compared to our surrogates (17.15 MPa) and calvaria (30.13 MPa).

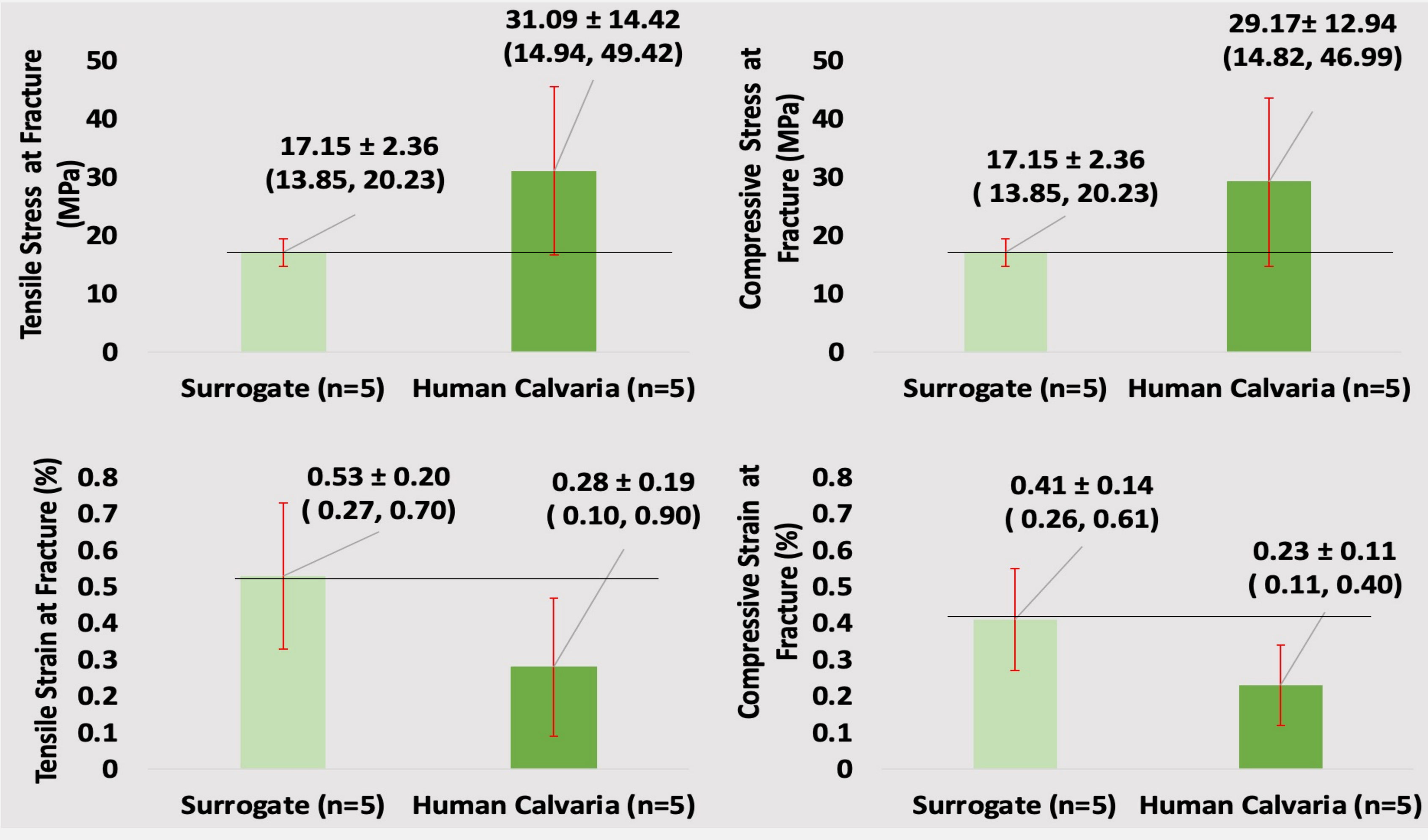

Figure 4. **Mean ± standard deviation (SD) (minimum value, maximum value) of stress and strain at fracture between the surrogate and calvaria.**

5. Conclusion and Ongoing Work

- Our surrogate model has the potential to model a skull fracture.
- Additional testing on surrogates and calvaria to perform statistical comparisons is ongoing.
- We are testing the surrogate in dynamic impact bending conditions so that the model's mechanical measurements at fracture are valid for strain rates applicable to real-world head impacts.

References

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