A Preliminary Step Towards a Calvarium Surrogate Model to Simulate Fracture

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Problem & Objective

When evaluating the risk of sustaining a traumatic head injury such as a skull fracture, research settings in forensic, sport, military, and automobile-safety may employ surrogate head models for injury reconstruction[1]. Surrogate head models are proven to be repeatable and reliable, however, they are often composed of rigid and non-deformable material[1]. This limits their ability to simulate skull fracture and reproduce mechanical properties comparable to the human skull. Research on surrogate models of the calvarium remains scarce[2-3], thus we must continue to explore design strategies for a surrogate model that can simulate skull fractures and be integrated with existing head models in the future. The objective of this study was to report on our preliminary beam design of a calvarium surrogate model and compare its mechanical response in quasi-static 4-point bending to human calvaria.

Methodology

Calvarium surrogate models (n=5) were fabricated as a 3-layer composite beam. The two outer layers were fabricated by mixing two-part epoxy and chalk with a thickness of 1.9 mm each. The middle layer was made of two-part epoxy with a thickness of 3.0 mm. Each layer was dried in a custom-made mold and then glued together using two-part epoxy to form adhesion between the layers. The surrogates were cured at room temperature for 2-weeks and tested in quasi-static 4-point bending (displacement rate: 2 mm/min). Surface strain was quantified on the outer layers using fibre Bragg gratings. Bending stress was estimated using the Euler-Bernoulli beam theorem. Surrogate bending moment, strain, and stress at fracture were compared to results of our preliminary quasi-static 4-point bending of human calvaria (n=5).

Results and Conclusions

Initial findings indicate that the mechanical response for the calvarium surrogate model is in the range of the calvaria samples (Table 1). We observed a brittle fracture that originated from the tensile surface of the surrogates like that observed in human calvaria. The next stages of the surrogate development include testing under impact loading and design modifications to achieve comparable averages with calvaria. Modifications can include geometry alterations such as thickness, adjusting the mixture ratio between epoxy and chalk, or considering different materials to construct the surrogate (e.g. Bonesim and hydroxyapatite).

Table 1. Mean ± SD and range (minimum value, maximum value) of mechanical response between the surrogate and calvaria.

	Bending Moment (N.m)	Strain (%)	Stress (MPa)
Surrogate	1.17 ± 0.18 (0.94, 1.36)	Outer surface: 0.41 ± 0.14 (0.26, 0.61) Inner surface: 0.53 ± 0.20 (0.27, 0.70)	17.15 ± 2.36 (13.85, 20.23)
Calvaria samples	2.45 ± 1.84 (0.71, 5.20)	Outer surface: 0.23 ± 0.11 (0.11, 0.40) Inner surface: 0.28 ± 0.19 (0.10, 0.60)	Outer surface: 29.17 ± 12.94 (14.82, 46.99) Inner surface: 31.09 ± 14.42 (14.94, 49.42)

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