The Effect of Surrogate Scalp Thickness on The Impact Response of a Physical Head Brain Model

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I. INTRODUCTION

Head surrogates are commonly used in head injury research and the evaluation of protective headwear [1]. Commercially available head surrogates can replicate the global kinematics of the human head under a range of loading conditions, but are often not adequate for replicating the intracranial responses which are important to further our understanding of brain injuries [1]. Head surrogates capable of replicating both the global kinematics and intracranial responses of the head require a more complex design with multiple components as well as a minimum level of anatomic details. The existence of a scalp has been found to dramatically alter head impact kinematics because it affects head mechanical properties [2], but the detailed influence of the surrogate scalp's physical parameters on head responses remains unclear. This work reports preliminary findings on the influence of one of the surrogate scalp's key parameters, the thickness, on the acceleration and intracranial pressure of a physical head model. This work is important to inform the future development of head surrogates capable of reproducing the global kinematics and intracranial responses of the human head.

II. METHODS

Materials

The Blast Injury Protection Evaluation Device Mark 1 (BIPED mk1), developed at Defence Research and Development Canada, was the physical head model used for this work. It comprises a scalp, two halved skulls, an instrumented brain, tentorium and falx, and saline water serving as cerebrospinal fluid (Fig. 1(a)). This head surrogate was originally developed for measuring intracranial pressure in blasts, but the ongoing development of the Mark 2 aims at extending its application to blunt impact conditions. The materials and dimensions of the head components were selected to match an average male human head while also considering practical factors such as ease of manufacturing and durability. The original scalp was made of Vytaflex 20 (Smooth-On Inc., CA, United States) with an average thickness of 6.35 mm. The Vytaflex 20 has a shore A hardness of 20, closing the reported average hardness (20.6) of human scalp [3]. Pads of four thicknesses (i.e. 2, 4, 6 and 8 mm) were moulded using Vytaflex 20 to replace the whole scalp in this study. These thicknesses cover a range of reported thicknesses of the human scalp (1–9 mm) [4]. The area of each pad (9 cm x 9 cm) was large enough to cover the impact region on the skull.

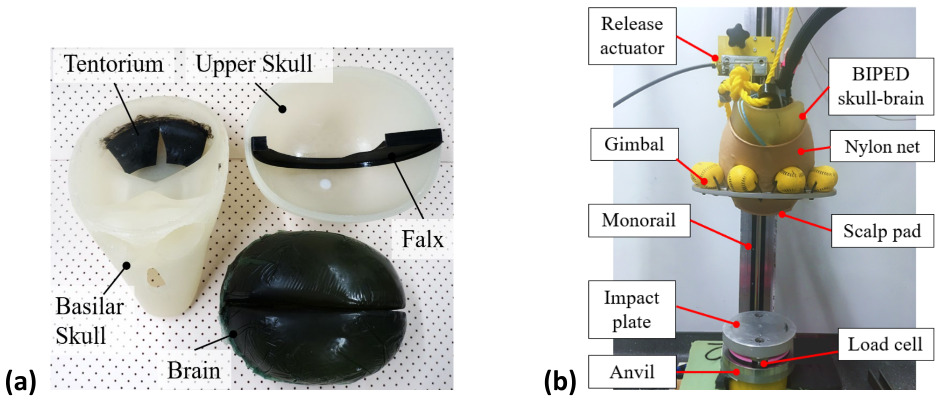

Fig. 1. (a) Major parts of BIPED mk1. (b) Drop impact test of the BIPED skull-brain attached to a scalp pad.

Drop Impact Experiments

Free-fall drop impacts were performed on the forehead of the BIPED using a monorail drop tower (Fig. 1(b)). The scalp pad was attached to the forehead of the BIPED using a nylon net. The BIPED was held in position using a gimbal and released onto an impact plate on the ground. A load cell (PCB 208C05, PCB Piezotronics Inc., NY, United States) under the impact plate captured the impact force. The coup pressure was monitored using a Kulite

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XCL-072 pressure sensor embedded in the front of the brain. Data were sampled at a rate of 25 kHz and filtered based on the SAE J211 [5]. Head accelerations were obtained by normalizing the impact force by the head mass (3.6 kg). Drop heights of 5 cm and 19.5 cm were evaluated for each pad, and each test was repeated three times.

III. INITIAL FINDINGS

Linear regression analysis with the thickness being the only independent variable confirmed that the scalp pad thickness influenced the peaks and durations of the acceleration and intracranial pressure of the head model. The pad thickness predicted 97% and 90% of the variation in peak acceleration for the impact height of 5 cm and 19.5 cm, respectively (Fig. 2(a)). The thickness explained over 97% of the variation in acceleration durations (Fig. 2(b)). Similarly, the thickness explained 85% and 92% of the variation in the peak pressure and over 98% of the variation in the pressure positive duration (Fig. 2(c) and (d)). All the regression models were significant ($p<0.05$) in rejecting the null hypothesis. Figure 2 shows the regression line and equation for each model. Peak acceleration and peak pressure were negatively correlated with thickness, while duration was positively correlated.

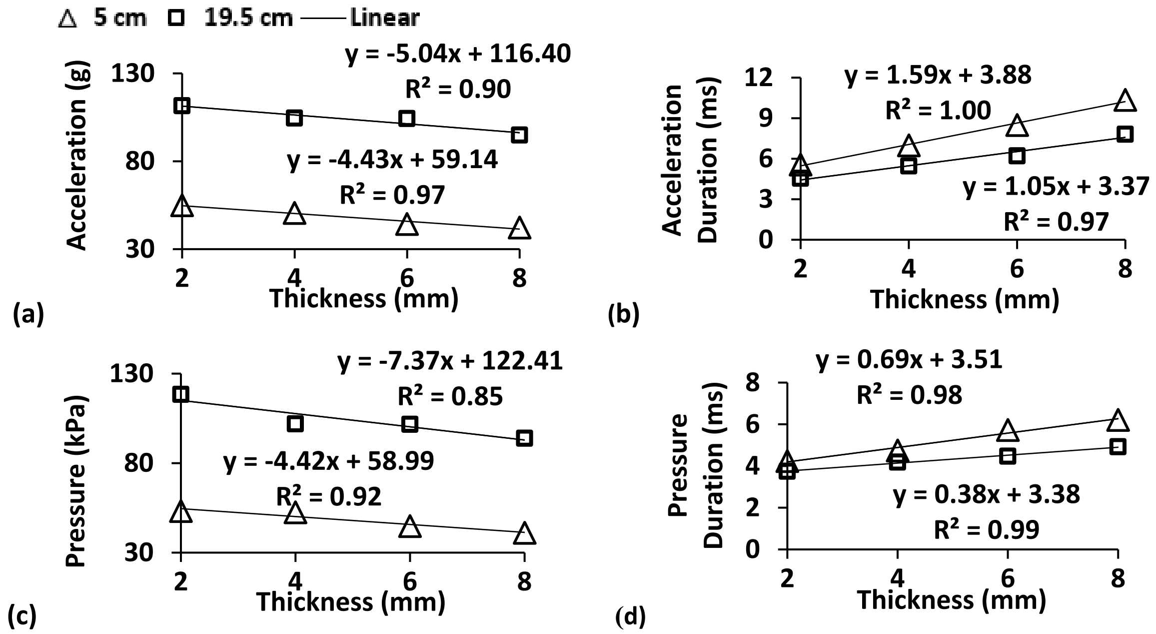

Fig. 2. Average accelerations and pressures of repeated tests plotted against the thickness.

IV. DISCUSSION

Based on our preliminary findings, scalp thickness significantly influenced the acceleration and coup intracranial pressure of the BIPED head model. This is because the impact responses depend on the head impact stiffness, which is partially governed by the scalp [6]. The scalp pad stiffness is negatively related to the thickness based on classical elasticity theory [7]. Thus, a slight alteration of the scalp thickness may lead to a significant change in the head impact stiffness and head responses. Our findings are limited to a scalp made of one material; therefore, future work will investigate the influence of scalp thickness using other candidate scalp surrogate materials. The present work can inform the design of scalps for head surrogates capable of mimicking global kinematics and intracranial responses of the human head.

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VI. REFERENCES

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