Evaluation of Female HBM Breast Tissue Models Using Isolated PMHS Breast Impact Experiments

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I. INTRODUCTION

Thoracic injuries are common for female occupants in motor vehicle collisions (MVCs) [1]. Interaction of breast tissue with modern safety systems, such as seat belts and airbags, may play an important role in female occupant kinematics and thoracic injury risk. Human body models (HBMs) can be used to better understand thoracic injury mechanisms. Female HBMs represent breast tissue using various adipose and skin models (Table I), but their ability to realistically represent female breast tissue response has not been explicitly assessed because breast biomechanical data relevant to the physical conditions of MVCs are limited [2]. The purpose of this study was to evaluate female breast tissue models from existing HBMs, as well as an updated GHBMC model, using isolated post-mortem human subject (PMHS) breast impact tests.

TABLE I

ADIPOSE AND SKIN DEFINITIONS USED IN CURRENT FEMALE HBMS AND TISSUE TESTS USED FOR DEVELOPMENT

	Adipose		Skin		
HBM	**LS-DYNA Material Model**	**Tissue Tests, Development**	**LS-DYNA Material Model**	**Tissue Tests, Development**	**Thickness (mm)**
GHBMC F05-O v6.0 [3]	Simplified Rubber	Porcine Adipose [4-5]	Ogden Rubber	Porcine Skin [5-7]	2.0
THUMS AF05 v7.1 [8]	Simplified Rubber	Human Adipose [8-9]	Fabric	Human Skin [8][10]	1.0
VIVA+ 50F v1.1.1 [11]	Ogden Rubber	Porcine Adipose [4][12]	Fabric	Human Skin [13]	1.0

II. METHODS

Experimental Testing

Bilateral breasts (n=2) were isolated from a 68-year-old mid-size female PMHS with a 36D bra size (Table II). Each breast was placed on a rigid plate and constrained by a custom fixture (Fig. 1). The centre of each breast was impacted by a 9 kg nylon impactor at 1 m/s using a vertical drop tower. Impact force was quantified using a single-axis load cell (Interface, 1210AF-5K-B), and the vertical displacement of the breast tissue was measured using 10,000 fps high-speed video tracking (TEMA, Image Systems Nordic AB).

Computational Modelling

The isolated breast impacts were simulated in a finite element (FE) environment (Fig. 2) using LS-DYNA (R11.2.2 MPP, Ansys). Simplified CAD geometry of a breast was developed using 3D scans of the experimental set-up. The adipose tissue was meshed using 2.5 mm brick elements. The outer surface of the adipose was coated in shell elements connected by shared nodes to represent the skin. Material, section, hourglass, and control cards were altered between simulations using definitions from the GHBMC, THUMS, and VIVA+ female HBMs (Table I). An additional updated GHBMC model used the same definitions as the GHBMC v6.0, but with a revised Ogden Rubber adipose material [9][14], adipose hourglass control, and skin thickness of 1.0 mm, which was similar to the PMHS and other HBMs (Table II). An impactor with the same dimensions, mass, and initial velocity as the experiments was included in the models. The force vs. deflection (FD) response of each model was compared to the experimental results. Stiffness was calculated using a linear spring potential energy method.

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TABLE II
BREAST SPECIMEN INFORMATION

Breast	Mass	Volume	Skin Thickness
	(g)	(cm³)	(mm)
PMHS L	1040	1210	0.8–2.2
PMHS R	930	1130	0.8–2.2
Models	885–1055	956–995	1.0–2.0

Fig. 1. Experimental set-up.

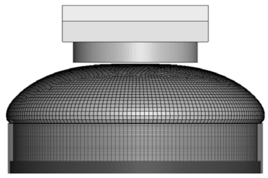

Fig. 2. FE model.

III. INITIAL FINDINGS

PMHS left and right breast FD responses were consistent (Fig. 3). All versions of the breast model were stable and reached normal termination. Simulation FD responses (Fig. 3), peak deflection, peak force, and stiffness varied depending on the properties applied (Fig. 4).

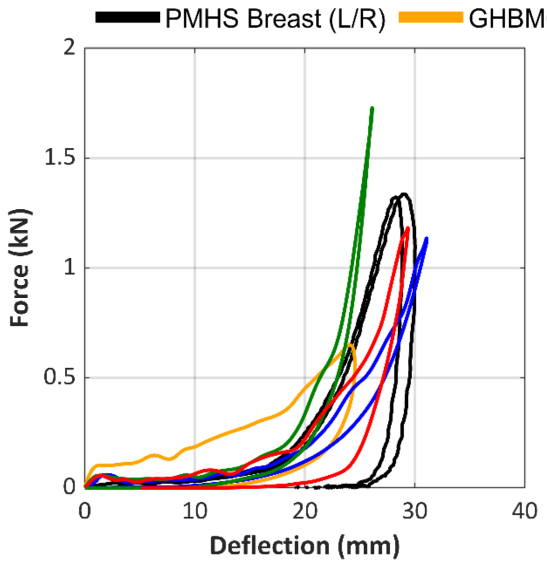

Fig. 3. FD responses.

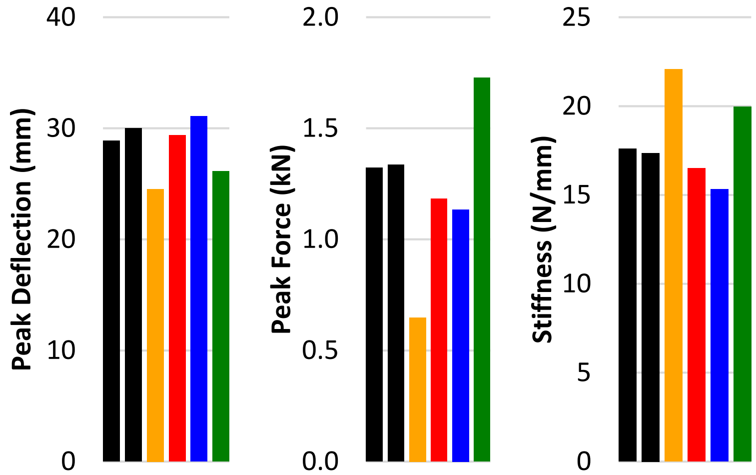

Fig. 4. Deflection, force, and stiffness comparisons.

IV. DISCUSSION

FD responses of the breast models using GHBMC v6.0 and VIVA+ definitions were qualitatively different from the PMHS responses. This discrepancy is likely due to the limited availability of female breast tissue biomechanical data. The updated GHBMC peak deflection, peak force, and stiffness were closest to the PMHS breasts, and the THUMS model was also similar. Material, section, and hourglass definitions used within these models may all be sensitive factors to consider for breast tissue response. The complex anatomical structure of female breast tissue [2] may warrant development of different material cards from those currently used for subcutaneous adipose tissue. More component-level and material-level physical testing should be completed using a larger sample size and various speeds to further enhance breast tissue modelling techniques in HBMs. These findings may have important implications for the potential importance of the breast tissue in female thoracic response.

V. REFERENCES

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