Development of Morphed Ribcage Finite Element Models for Comparison with PMHS Data

D. Jastrzębski, D. Poulard, M.B. Panzer

I. INTRODUCTION

Finite element (FE) human body models (HBMs) are used to better understand how injuries occur in the thorax during impact [1-3]. Development and validation of the ribcage in HBMs using detailed data are necessary to ensure that the models can mimic the load distribution through the thorax. As post-mortem human subjects (PMHSs) differ in anthropometry across subjects, it is believed that the biofidelity of HBMs cannot be properly evaluated by comparing a generic anthropometry model against the specific PMHS test data [4]. Differences between PMHS and HBM include material properties and geometry. However, geometric morphing techniques enable the development of personalized models that alter a ribcage geometry to match specific PMHS anatomy, and to reduce part of the uncertainty between HBM and PMHS. The goal of the current study is to present a method to morph FE ribcages and evaluate the potential benefit by comparing model mechanical responses against PMHS test results.

II. METHODS

The AM50 THUMS pedestrian [5] ribcage was used as a baseline, and a morphed ribcage was created to the anthropometric specification of one of the PMHS ribcage (woman, 61 years old, height: 1.74m, mass: 82.6kg) used in point loading of the eviscerated ribcage [6]. The morphing procedure was based on a Dual Kriging interpolation [7] process. A total of 181 control points for morphing were extracted by numerically slicing each rib (from four to 12 slices) along their respective longitudinal axis, and for the sternum by manually selecting from characteristic points of a part. The morphing was then applied on the sternum and each rib independently. Morphed ribs were repositioned using landmarks taken on CT to ensure a correct position of each part of the ribcage (Fig. 1). The geometrical accuracy of the method was calculated for each rib and sternum using the average of all distances calculated between the model ribcage (either baseline or morphed) and the CT computed for each point of the reference geometry to the closest point of each part of the ribcage (Table 1).

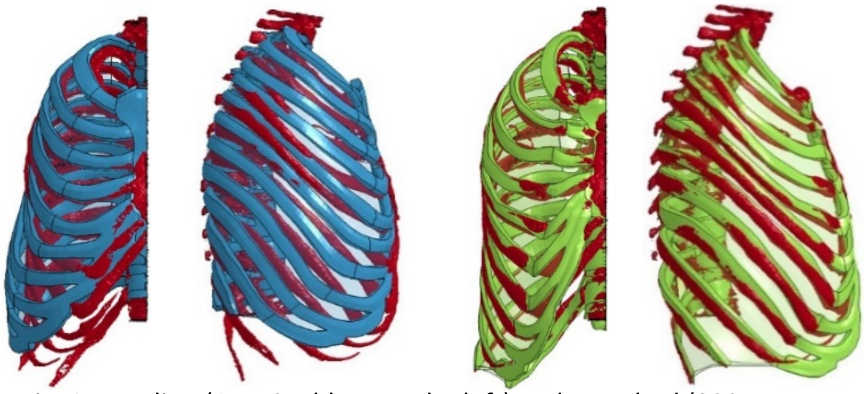

Fig. 1. Baseline (AM50 – blue, on the left) and morphed (229-F, green on the right) ribcage models compared to CT (red) for reference

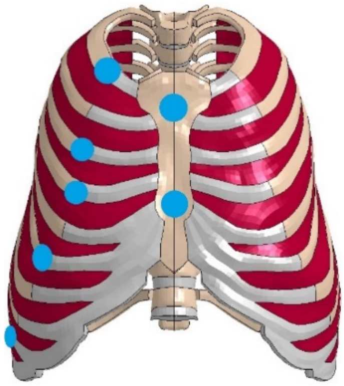

Fig. 2. Point loading positions of the eviscerated ribcage

The ribcage was quasi-statically loaded locally to a non-failure displacement (nominally 15% of the ribcage depth at the loaded rib level) at seven loading sites (Fig. 2). The reaction force onto this plate was plotted

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against its applied displacement and the experimental results were compared using Root Mean Square Error (RMSE).

Table 1: Average geometric error at individual level for baseline and morphed model (mm)

	Rib 1	Rib 2	Rib 3	Rib 4	Rib 5	Rib 6	Rib 7	Rib 8	Rib 9	Rib 10	Rib 11	Rib 12	Sternum	Average
Baseline	0.77	1.15	1.01	1.08	1.46	1.63	3.02	3.31	3.30	3.06	2.37	2.88	1.34	**2.21**
Morphed	0.33	0.24	0.24	0.29	0.31	0.34	0.35	0.30	0.29	0.22	0.24	0.23	0.18	**0.28**

III. INITIAL FINDINGS

Examples of force versus displacement curves predicted are shown in Fig.3.

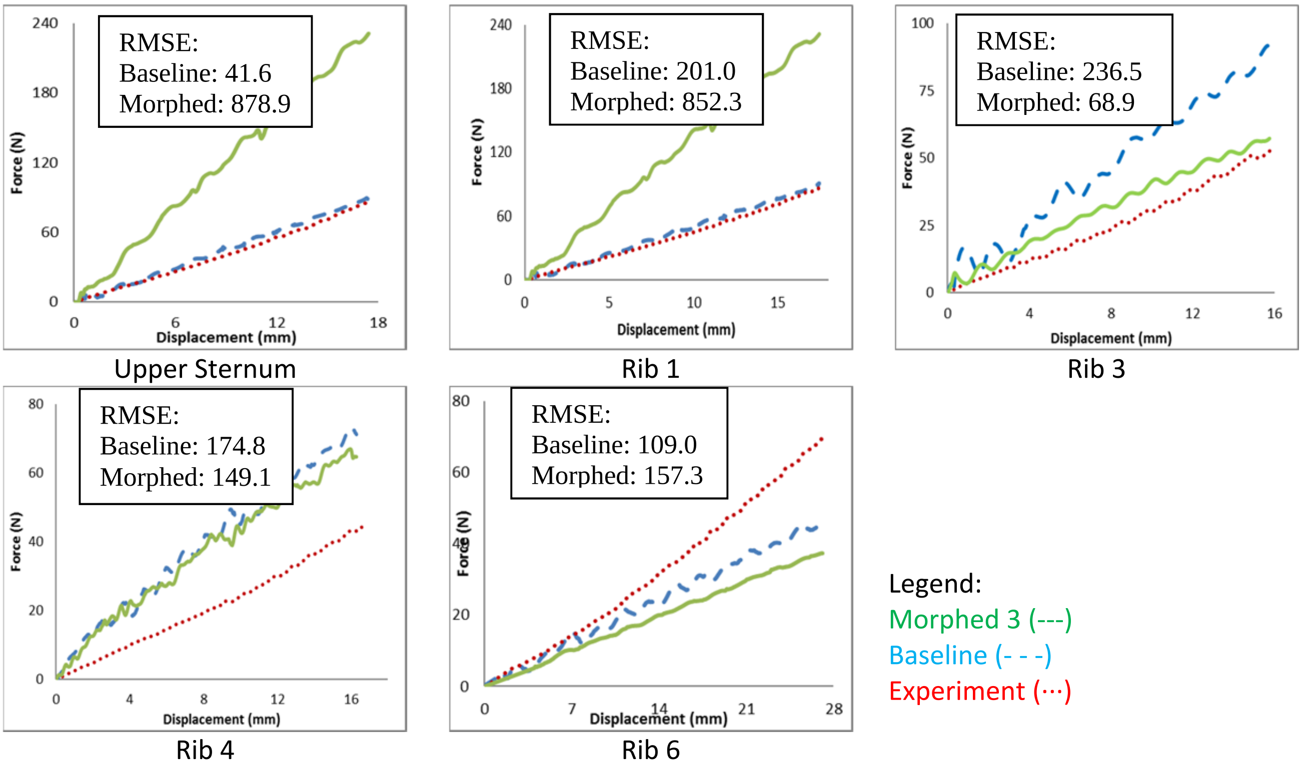

Fig. 3. Model performance for point loading of the denuded ribcage.

IV. DISCUSSION

Matching the ribcage geometry only improved the mechanical response in 2 of 7 cases (Fig. 3). The inability of the morphed models to capture the experimental response indicates that material properties and other structural details such as cortical bone thickness part an equally essential role in the personalization of HBMs. In the future, it is planned to map the correct thickness to each node of the rib cortical bone mesh for a potential increase in biofidelity. A sensitivity analysis on bone material properties will be also performed to evaluate what is the contribution of ribcage geometry on mechanical response in this specific configuration.

V. REFERENCES

[1] Gayzik FS et al, SAE, 2009
[2] Iwamoto M et al, IRCOBI, 2002
[3] Poulard D et al, JMMBM, 2015
[4] Poulard D et al, SAE, 2016
[5] THUMS User Manual
[6] Kindig MW et al, Stapp Car Crash J, 2010
[7] Trochu F, Engineering with computers, 1993
[8] Perz R et al., JMBBM, 2015

Erratum

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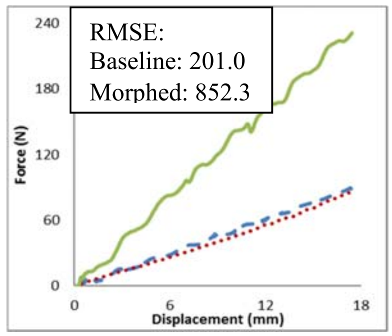
Fig. 3, Rib 1 plot from:



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