Lateral Bending Response Corridors for the 5th Rib of a 50th Percentile Male Finite Element Model.

Jacek Toczyski, David Poulard, Therese Fuchs, Steffen Peldschus, Jason Forman

I. INTRODUCTION

Finite Element (FE) Human Body Models (HBM) are commonly used to better understand how injuries occur. One of the challenges in using HBM is that they can differ between each other, and a simulation run with one of the models may give different results than a simulation run with another FE model. Because of that one of the goals for the biomechanics computational community should be to standardize the manner in which human body models are validated. The validation scheme should vary from simple load cases targeting individual body regions (with simple boundary conditions) to more complicated test environments (e.g. sled tests). Standardizing validation methods presents a challenge, though. Oftentimes models require manual manipulation or user's judgement during positioning, settling, etc. Consistent execution of these steps requires precise and detailed step-by-step instructions for the validation environment setup and analysis. For this purpose response goals for the model are also required. The goal of this study was to use a simple load case (lateral bending of a left 5th rib) to explore methods to specify, document, and communicate a component-level biofidelity evaluation protocol for application to an HBM.

II. METHODS

Experimental data available in open literature [1] were used for preparation of two force-related response corridors. The experimental study focused on lateral loading of a single intact rib to failure at a dynamic loading rate. Three left 5th ribs taken from three different post-mortem human surrogates (PMHS) (mean age, standard deviation (SD): 64 years, 7.3) anthropometrically close to a 50th percentile male were used. Four strain gauges were put on the cortical bone of each rib. The strain gauges were located approximately ±40 mm off the loading point (along the rib curvature) on the lateral and medial side of the rib. Reaction forces at both rib ends, strains, and the loader displacement were measured during the experiment.

Preparation of Response Corridors

To create a corridor, three different unscaled response curves were used. To avoid artificial effect of data drop-out due to fracture, all curves were trimmed at the same loader displacement just before the fracture occurred for the specimen with the smallest displacement-to-fracture.

Two corridors were developed: force-displacement corridor (Fig. 1) to make sure that the overall rib stiffness will be represented correctly in the FE model and a force-strain corridor (Fig. 2) to emphasize the importance of a proper material model used for the rib behavior prediction. Each corridor consists of two main parts:

- Response corridor before fracture (called here *Ellipsoid Corridor*), following the experimental test curves, built using the ellipse-based method described in detail in [2-3],
- Fracture occurrence corridor, built as a simple ±1 standard deviation rectangular corridor. SD for the corridor was calculated in both directions (either for force and displacement or for force and strain). The average force and loader displacement (or measured strain), at which the fracture occurred, were calculated based on the fracture values recorded on the experimental tests.

III. 5TH RIB RESPONSE CORRIDORS

Based on the experimental test data two response corridors, i.e. one force-displacement (Fig. 1) corridor for

* J. Toczyski is a PhD student in Mechanical Engineering at University of Virginia, VA, USA (tel: +1 434-297-8069, fax: +1 434-297-8083,
e-mail: jt6dt@virginia.edu). D. Poulard is a Research Associate and J. Forman is a Principal Scientist at the University of Virginia Center for Applied Biomechanics, VA, USA. T. Fuchs is a PhD candidate at University of Munich, Germany. S. Peldschus is a Professor at Furtwangen University of Appl. Sciences and a researcher at University of Munich, Germany.

the anterior rib end, and one force-strain corridor (Fig. 2), were created.

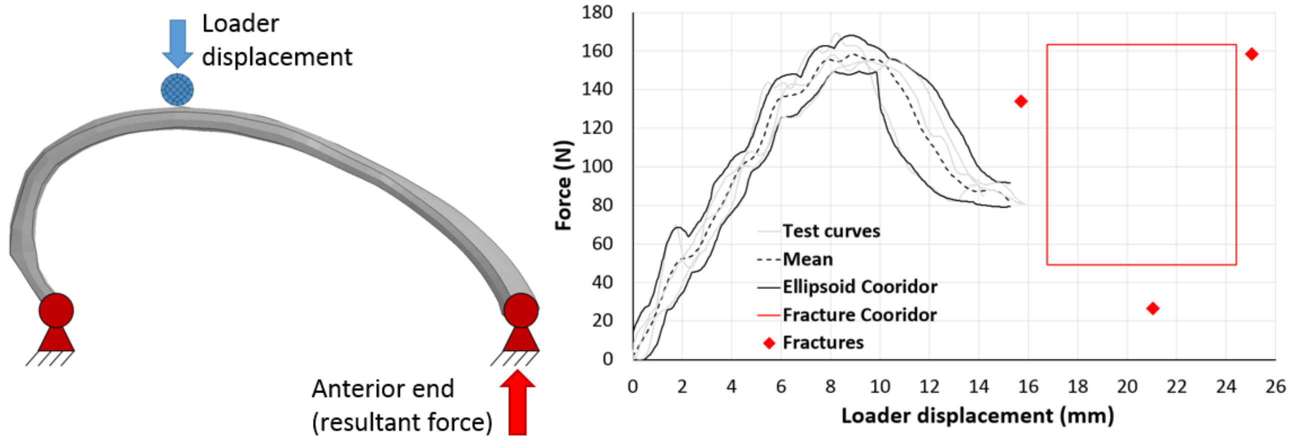

Figure 1. Force-displacement corridor for the anterior rib end

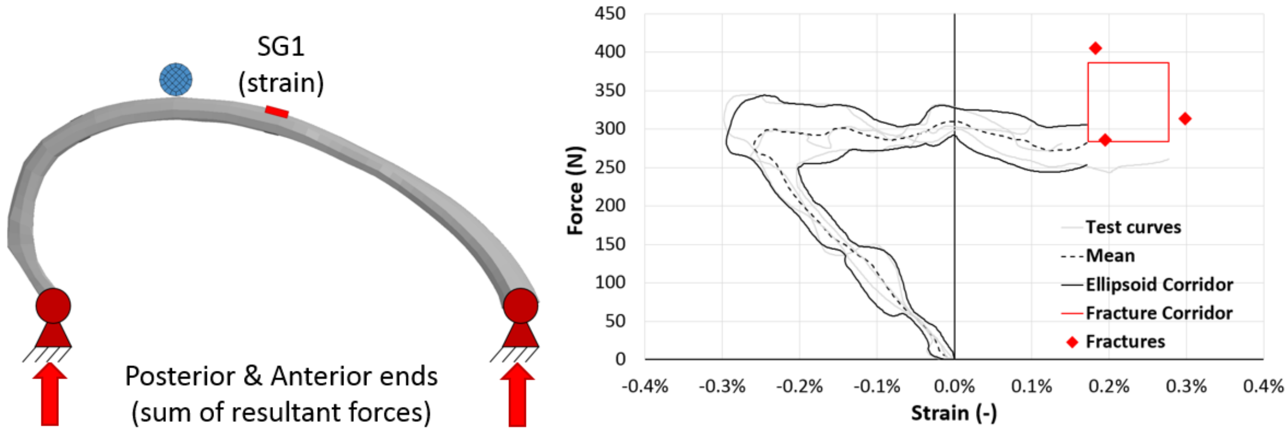

Figure 2. Force-strain corridor for one of the strain gauges used on the tests [1]

IV. DISCUSSION

Given the bi-modal shape of the force-displacement corridor (Figure 1), achieving model responses fitting the given corridors using simple material models may be a challenge. Focus should be put on parts of the corridors applicable to the goals of the modeling task. For example, if the model is intended to capture the linear response of the rib under limited deformation, then it may be adequate to consider only the first 6 mm of the force-displacement corridor where the response is linear. If the user wants to model the rib response under large deformation, including material and geometric nonlinearities after the first force peak, the corridors should be considered throughout their entire length.

Developing standardized HBM validation environments from prior experimental studies can present a challenge if the experimental methods are not documented in sufficient detail or if there are methodological inconsistencies between tests. Because biomechanical experimentation is relatively rare and carries a wide range of specimen-to-specimen variability, care should be taken to design and document experiments with consideration for potential use in model validation in the future (even if that is not the immediate goal). This should include detailed 3D geometric digitization of the specimens and test setup whenever possible.

V. ACKNOWLEDGMENTS

For completing this study, the authors acknowledge the support of THUMS Users Community, a project of LMU in cooperation with Adam Opel AG, AUDI AG, BMW AG, Autoliv, Daimler AG, Dr. Ing. h.c.F. Porsche AG, Toyota Motor Corporation and Volkswagen Aktiengesellschaft.

VI. REFERENCES

[1] del Pozo E e al, Intern. JCrashworth, 2011
[2] Ash J e al, IRCOBI, 2012
[3] Zhang Q e al, JBiomech, 2014