TUC Validation Repository

-

Documentation
Validation Environment
VPS

Femur: Dynamic 3-Point Bending

Version: V01

VPS version provided by: University of Munich (LMU) / AUDI AG

Last updated: August 30, 2019

Experimental data provided by: Jason Forman, University of Virginia

Contact Person: Sonja Schneider, University of Munich (LMU) / AUDI AG
sonja.schneider@audi.de

1. General

This document is part of the *validation kit* for the validation of a FE Human Body Model (HBM) against the loading condition specified under 1.1. The *validation kit* is composed of the following parts:

1. FE model of **validation environment**

   The following VPS files contain the validation environment:

   a. *TUC_EX_FEMUR_MED_MAIN.pc*
   b. *TUC_EX_ FEMUR _ MED _OUTPUT.inc*
   c. *TUC_EX_ FEMUR _ MED _BCs.inc*
   d. *TUC_EX_ FEMUR _ MED _GEOMETRY.inc*

   The HBM to be validated needs to be prepared and integrated into the validation environment according to the validation protocol in section 4.

2. Experimental corridors

   Experimental corridors will be provided in a later update of the validation kit.

3. Validation Protocol incl. a description of the load case

   The validation protocol describes the associated experiment briefly and shows how the femur model to be validated needs to be integrated into the validation environment. It will be provided separately for download.

1.1 Classification of validation load case

Body region	Extremity
Level	Component
Load case	Dynamic 3-Point Bending of isolated Femur
References	**Experimental test description :** Forman, Jason L., et al. "Fracture tolerance related to skeletal development and aging throughout life: 3-point bending of human femurs." *IRCOBI Conference Proceedings, Dublin, Ireland. 2012.* **Experimental test results:** Park, G. (2017): Injury Risk Functions Based on Responses of Population-Based Finite Element Models: Application to Femurs under Dynamic Loading. *PhD Thesis*. Park, Gwansik, et al. "Injury risk functions based on population-based finite element model responses: Application to femurs under dynamic three-point bending." *Traffic injury prevention 19.sup1 (2018): S59-S64.* **Simulation:** Schneider, Sonja, Forman, Jason, Peldschus, Steffen (2021) "Complementing femur model validation with a variability-focused approach", *Traffic Injury Prevention Vol. 22*, DOI: 10.1080/15389588.2021.1982598
Unit system	kg - mm – ms – kN – GPa
Code	VPS (Virtual Performance Solution)

1.2 Disclaimer

The validation kit was developed in close cooperation within the THUMS USER COMMUNITY (TUC) research project. Any use of this validation environment shall be entirely at the user's own risk and responsibility. University of Munich (LMU), Adam Opel AG, AUDI AG, Autoliv, BMW AG, Daimler AG, Porsche AG, Toyota Motor Corporation and Volkswagen AG do not assume any responsibility for the validity, accuracy, or applicability of any results obtained from this research model and do not assume any liability or responsibility whatsoever for any damage, claims, injury or loss of any kind that may arise from or in connection with any use of, reference to and/or reliance upon this manual.

University of Munich (LMU), Adam Opel AG, AUDI AG, Autoliv, BMW AG, Daimler AG, Porsche AG, Toyota Motor Corporation and Volkswagen AG ask that the TUC project will be acknowledged under references for any use of this FE model resulting in papers and publications.

2. Short description of experimental setup and selection of configuration

In the experimental study of Forman et al. [1] dynamic 3-point bending tests of the femur were conducted at a constant loading rate of 1.5 m/s using a padded impactor. The padding was characterized in [2]. The experimental time history curves are published in [2], [3]. Due to the courtesy of Jason Forman (University of Virginia), the drawings of the parts used in the experimental setup were provided for creating a realistic virtual representation of the experimental setup.

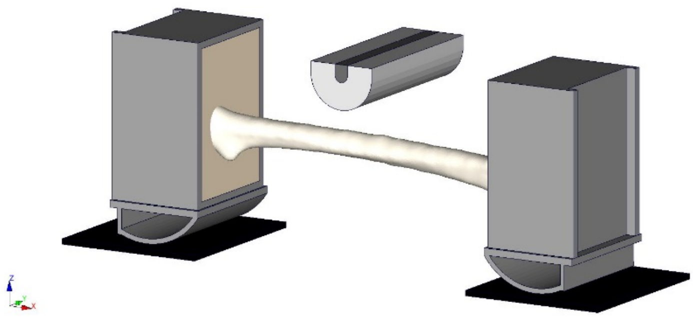

Figure 1 Numerical representation of the experimental setup used in [1] with a femur model of the LMU database

There were 23 bones tested in this study, whereas 7 bones were < 10 years and not regarded further in the development of this setup. For 15 adult male specimen the time history curves are provided in [2], [3].

All details about the specimens regarding age, bone length and section properties at mid-shaft of the femur can be found in the referenced literature.

3. Description of the Validation Environment

In this section the validation environment, i.e. the numerical model of the experimental setup excluding the HBM to be validated, is described. For each of the above mentioned input decks a short description of the file contents is given. The protocol of section 4 describes how a human body model needs to be processed to be integrated in and validated with this environment FE model.

3.1 *TUC_EX_FEMUR_MED_MAIN.pc* - main file

The main file contains a simulation header specifying the used solver Virtual Performance Solution (VPS) Version 2015, the solver type is set to CRASH and the analysis type is set to be EXPLICIT. Control cards delivered with the HBM itself are to be used and specified in this main file. The termination time for the solver is defined to 60 ms.

Further, all include files of the validation environment are specified in this main file:

- *TUC_EX_FEMUR_MED _GEOMETRY.inc,*
- *TUC_EX_FEMUR_ MED _BCs.inc,*
- *TUC_EX_FEMUR_ MED _OUTPUT.inc.*

3.2 *TUC_EX_FEMUR_ MED _GEOMETRY.inc* – Impactor / Padding / Rollers / Embedding / Ground

In this file the geometry (part-, element-, node- and material definitions) of the following setup components are specified:

Part	Part-ID	Material-ID
Impactor	8	3
Impactor Padding	9	1
Embedding Blocks	3 (proximal roller), 6 (distal roller)	2
Roller	1/2 (proximal roller), 4/5 (distal roller)	4
Ground Plates	7	4

The impactor is modelled with a diameter of 13 mm [1] and material properties of aluminum. The padding is modelled with a thickness of 25 mm [1] and compression characteristics presented in [2]. The embedding blocks are modelled as Null Material Solids as they are only used as Rigid Bodies (RBEs). Therefore only the density of the PMMA Material is specified to 1.0 g/cm^3. A 3D geometry model was preferred over a 2D one for the rollers due to the more realistic representation of the geometry and mass inertia behavior. The rollers and ground plates are modelled as 3D geometries with steel material characterization. The parts of the proximal roller (Part-IDs: 1,2,3) and distal roller (Part-IDs: 4,5,6) are modelled such that the interfaces between parts have shared nodes to model an ideal connection between those parts.

3.3 *TUC_EX_FEMUR_ MED _BCs.inc* – Boundary Conditions

The following boundary conditions and constraints are defined in the validation environment.

3.3.1 Contact Definitions

A symmetric node-to-segment with edge treatment contact was defined for contact modelling between the rollers and the ground plates (CNT-ID: 1), between the impactor and its padding (CNT-ID: 3) as well as to model the contact between the padding and the bone (CNT-ID: 4). Further, an internal solid anti-collapse contact (CNT 10) had to be defined for the padding (CNT-ID: 2) due to the strong compression of the padding. This strong compression causes numerical instabilities if this self-contact is not defined. This anti-collapse contact was defined to add numerical stiffness when the element is compressed to 90% of the element length.

3.3.2 Rigid Body (RBE) Definitions

The impactor has a higher stiffness as the bone. Therefore it is modelled as a Rigid Body (RBE-ID: 4). The interface nodes on the padding side are included in this RBE definition to model a strong interface between impactor and padding. The ground plates are also modelled as RBEs (RBE-ID: 3). For the rollers (RBE-IDs: 1,2) there exist two options (see ***Figure 2***): either the whole roller is modelled as a RBE or only the upper part of the roller is included in the RBE definition. As the standard configuration provided in this setup the whole roller is modelled as RBE. When the lower part of the roller is excluded from the RBE definition one has to be aware that the setup is very sensitive to specified control cards in the main file regarding mass scaling.

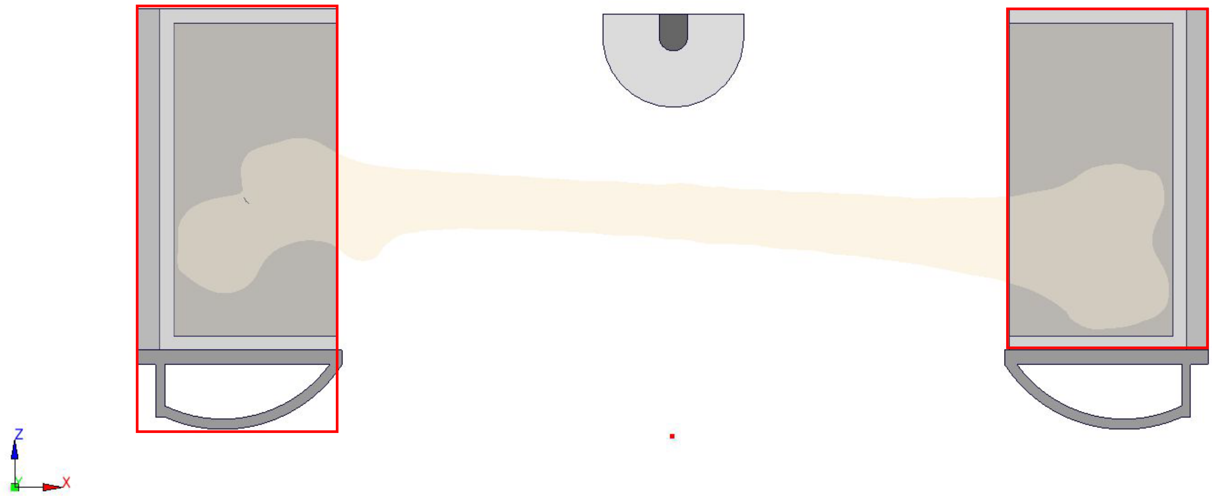

Figure 2 - Possibilities for Rigid Body Definition

In the RBE definitions of the rollers also the nodes of the bone ends have to be included.

3.3.3 Setup Constraints

On the center of gravity node of the defined RBE of the impactor (RBE-ID: 4) an initial velocity of 1.5 m/s was defined. Additionally, a constant velocity of 1.5 m/s was defined on this center of gravity node to completely characterize the impactor movement. Last but not least, a displacement constraint was applied on this center of gravity node to only allow downward movement of the impactor.

The center of gravity node of the defined RBE of the ground plates was completely constrained regarding its movement.

3.4 *TUC_EX_FEMUR_ MED _OUTPUT.inc* – output definitions

The following output parameters are defined in the validation environment.

A nodal time history output was defined for the center of gravity node of the RBE defined for the Impactor (RBE-ID: 4). This output was defined to check that the impactor movement was correct.

Further, a section force output was defined to measure the contact force between the rollers and the ground. This section force output is a force-time history output and has to be compared to the experimental results.

References

[1] Forman, Jason L., et al. Fracture Tolerance Related to Skeletal Development and Aging Throughout Life: 3-Point Bending of Human Femurs. IRCOBI Conference Proceedings, Dublin, Ireland. 2012 2012.

[2] Park, G. 2017. *Injury Risk Functions Based on Responses of Population-Based Finite Element Models: Application to Femurs under Dynamic Loading*. *PhD Thesis*.

[3] Park, G., Forman, J., Kim, T., Panzer, M. B., and Crandall, J. R. 2018. Injury risk functions based on population-based finite element model responses. Application to femurs under dynamic three-point bending. *Traffic injury prevention* 19, sup1, S59-S64.