

# TUC Validation Repository

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## Load Case Description & Validation Protocol

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# Lumbar Intervertebral Disk: Compression

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<b>Version:</b>	V01
<b>VPS version provided by:</b>	University of Munich (LMU) / BMW AG
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## 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 LS Dyna files contain the validation environment:

- a. *main.k*
- b. *bc.k*
- c. *geom.k*
- d. *control.k*
- e. *out.k*

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

The following experimental corridors are provided as excel-files:

- f. *Fo\_M01.csv – Fo\_M15.csv*
- g. *Convex\_Hull.csv*
- h. *Convex\_Hull\_FailurePoints.csv*
- i. *Corridor\_Mean\_Values.csv*
- j. *Corridor\_Mean\_plusSTD.csv*
- k. *Corridor\_Mean\_minusSTD.csv*

### 3. Documentation incl. a detailed description of the load case and a validation protocol

## 1.1 Classification of validation load case

<b>Body region</b>	Thorax
<b>Level</b>	Component
<b>Load case</b>	Dynamic Axial Compression of an Intervertebral Disk
<b>References</b>	Christou, A., Grigoriadis, G., Carpanen, D., Newell, N., & Masouros, S. D. (2017). Biomechanics of a lumbar functional unit using the finite element method. IRCOB Conference 2017, 668–669.
<b>Unit system</b>	kg - mm – ms – kN – GPa
<b>Code</b>	LS Dyna 9.3.0

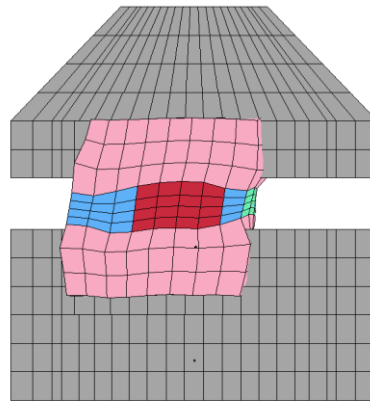
## 1.2 Disclaimer

The validation kit was developed in close cooperation within the THUMS USER COMMUNITY 2 (TUC2) research project. Any use of this validation environment shall be entirely at the user's own risk and responsibility. University of Munich (LMU), AUDI AG, Autoliv, BMW AG, Daimler AG, Porsche AG, Toyota Motor Corporation, Volkswagen AG and ZF TRW 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), AUDI AG, Autoliv, BMW AG, Daimler AG, Porsche AG, Toyota Motor Corporation, Volkswagen AG and ZF TRW ask that the TUC 2 project will be acknowledged under references for any use of this FE model resulting in papers and publications.

## 2. Short description of experimental setup

In the experimental study of Newell et al. [1] dynamic tests of intervertebral disks (IVDs) were conducted at a constant loading rate of 1 m/s using a material testing machine. A drawing of the parts used in the experimental setup were provided for creating a realistic virtual representation of the experimental setup (see [Figure 1](#)).



**Figure 1** Numerical representation of the experimental setup used in [1]

There were 16 specimens tested in this study. The 16 specimens are four lumbar levels harvested from four individuals.

All details about the specimens regarding age, health, and geometry are given in [Table 1](#).

**Table 1** Overview of the specimen reference data

	Min. Value	Max. Value	Mean Value	Std. Deviation
<b>Age [years]</b>	22	58	40	18
<b>Average Pfirrmann Grade</b>	1.6	4.0	2.67	0.45
<b>Central Disk Height [mm]</b>	7.3	12.8	10.2	1.7
<b>Disk Width Anterior-Posterior [mm]</b>	33.4	45.2	39.8	3.8
<b>Disk Width Lateral [mm]</b>	44.8	59.6	53.8	4.2

### 3. Description of the Validation Environment

In this section the validation environment is described, including the numerical model of the experimental setup without the HBM to be validated. 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 *main.k* - main file

The main file contains only the termination time and the other include files. The termination time for the solver is defined to 60 ms. This entire simulation setup has been prepared in the S2 units system: mm-ton-s.

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

- *geom.k*
- *bc.k*,
- *out.k*
- *control.k*
- *IVD.k*

Where IVD.k is the prepared HBM component file.

#### 3.2 *geom.k* – Model Geometry Including Pots and Potting Material

In this file the geometry (part-, element-, node- and material definitions) of the following setup components are specified (see [Table 2](#)):

**Table 2** - Content of file 'geom.k'

Part	Part-ID	Material-ID
Lower Potting	1	1
Upper Potting	2	1
Upper Pot	3	2
Lower Pot	4	2

The pots were modelled with a diameter of 60 mm and the material properties of aluminum. The potting was modelled with a diameter of 60 mm and the material properties of PMMA. The potting blocks were modelled as a rigid material. Therefore only the density of the PMMA Material is needed, and is specified at 1.18 g/cm<sup>3</sup>. The specimen is attached to the potting material using \*CONSTRAINED\_RIGID\_BODIES cards as described in section 3.3.

### 3.3 *bc.k* – Boundary Conditions

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

#### 3.3.1 Rigid Body Definitions

It is assumed that the structural stiffness of the potting is sufficient high such that it can be modelled as a Rigid Body. This is because in addition to the potting material the specimens were also held in place with bone screws. Also as the loading does not reach the destructive domain, many dynamic effects can be assumed to be negligible. The interface elements belonging to the cortical bone (for models with deformable vertebrae) are redefined as rigid elements and then joined to the potting using a \*CONSTRAINED\_RIGID\_BODIES card.

### 3.3.2 Setup Constraints

A prescribed motion was given to all of the nodes on the upper surface of the upper pot in the Z direction. This motion was extracted from the LVDT data and constructed of average depending on the spinal segment level. The lower edge of the bottom pot is held fixed using a Single Point Constraint boundary condition for all degrees of freedom.

### 3.3.3 Contacts

No contacts are defined for this validation setup as to not interfere with the rigid body constraints.

## 3.4 *out.k* – Output Definitions

The following output parameters are defined in the validation environment.

A nodal time history output was defined for the center of the upper surface of the upper pot. This output was defined to check that the impactor movement was correct.

Further, a section force output was defined to measure the contact force flowing through the upper pot. This section force output is a force-time history output and is used to make comparisons to the experimental results.

## 3.5 *control.k* – control cards

The control cards associated with the HBM being simulated are located in control.k.

## 4. Validation Protocol

The following validation protocol is a step-by-step procedure to safeguard a credible validation of any HBM this validation environment is used for. The protocol is composed of three parts containing the following information:

1. **Pre-processing**

In section 4.1 it is described how the human model needs to be prepared and positioned in the above described validation environment to meet the specifications in the reference paper.

2. **Solution**

Chosen control parameters, hardware and solver version are listed in section 4.2.

3. **Post-processing**

Section 4.3 describes how experimental data were prepared and how simulation results need to be processed to guarantee a reasonable validation.

It is envisaged that the following protocol can be applied to any HBM which is to be validated against the above mentioned loading condition. However, the provided FE model of the validation environment was setup with **THUMS TUC, THUMS v4, THUMS v5 GHBM C M50 Occupant Model Version 4.4, and the ViVa Model.**

## 4.1 PRE-PROCESSING

This section describes how the human model needs to be prepared and positioned in the above described validation environment and what other adaptations need to be done to meet the specifications in the reference paper.

Note: A femur model created from the LMU database was used to illustrate the positioning process.

### 4.1.1 Isolation, Positioning and Integration of the Human Body Model

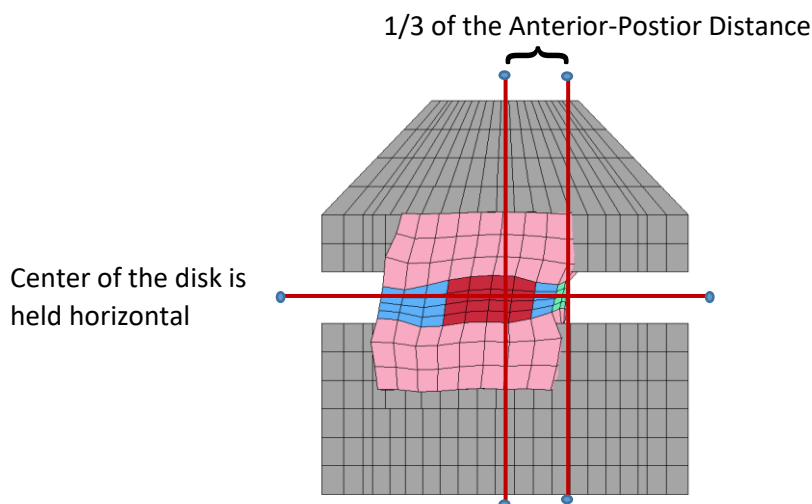
The following steps have to be done to prepare and position the HBM in the above described validation environment to meet the specifications in the reference paper. It is recommended to put all HBM relevant data in an additional VPS include file (e.g. HBM.inc) and reference the include file in the main file.

#### 1. Isolation of validation-relevant components

The HBM needs to be prepared according to the specimen preparations done in the experimental study. All relevant parts of the IVD to be investigated needs to be extracted from the HBM and saved into the additional include file. Relevant parts are the part definitions of the nucleus, annulus, annulus fibers, and vertebrae, as well as the material definitions with its embedded function definitions. The posterior elements of each functional spine unit must be excised in order to avoid problematic contacts.

#### 2. Positioning of the isolated femur in the validation environment

To correctly position the IVD the disk must be positioned perpendicular to the applied force, so the disk must be aligned as horizontal. The line of action of the applied force, which can be thought of as a vertical line running from the center of the upper surface of the top pot, must pass through the IVD at a location 1/3 of the anterior posterior distance from the most posterior aspect of the disk. A diagram showing the positioning parameters can be seen in [Figure 2](#).



**Figure 2** - Positioning of the femur in the experimental setup

### 4.1.2 Constraints

The following constraints defined in the input file of the boundary conditions need to be adapted depending on the HBM used.

### a. Potting

For models with deformable bones, the Rigid Body attachments are made by converting the deformable shells of the cortical bone to rigid shells, but only for the shells which would have a bond to the potting material. These shells are then connected to the rigid potting materials using \*CONSTRAINED\_RIGID\_BODIES cards. For models without deformable bones, the rigid cortical bone can be connected to the potting directly with \*CONSTRAINED\_RIGID\_BODIES cards. Care should be taken to make sure the upper vertebrae is connected to the upper pot, and vice versa.

## 4.2 SOLUTION

LSDYNA Version 9.3.0 using single precision was used to setup and run the validation model with **THUMS TUC, THUMS v4, THUMS v5 GHBMC M50 Occupant Model Version 4.4, and ViVa Models.**

## POST-PROCESSING

### 4.2.1 Model check

Before comparing the model response against the experimental corridors, the user should check first:

- a. The energy balance such that the total internal energy (sum of total internal energy, kinetic energy, contact work) is equal to the external work brought into the system
- b. If mass scaling is used, the system added mass is less than 3% of its physical mass
- c. The ratio of the hourglass energy to the maximum internal energy of the whole system should be < 10%
- d. The ratio of the hourglass energy to each part of the system should be < 10 %
- e. The frictional energy is positive due to friction, not negative due to initial penetrations in contact
- f. The kinetic energy is substantially lower as the total energy of the system

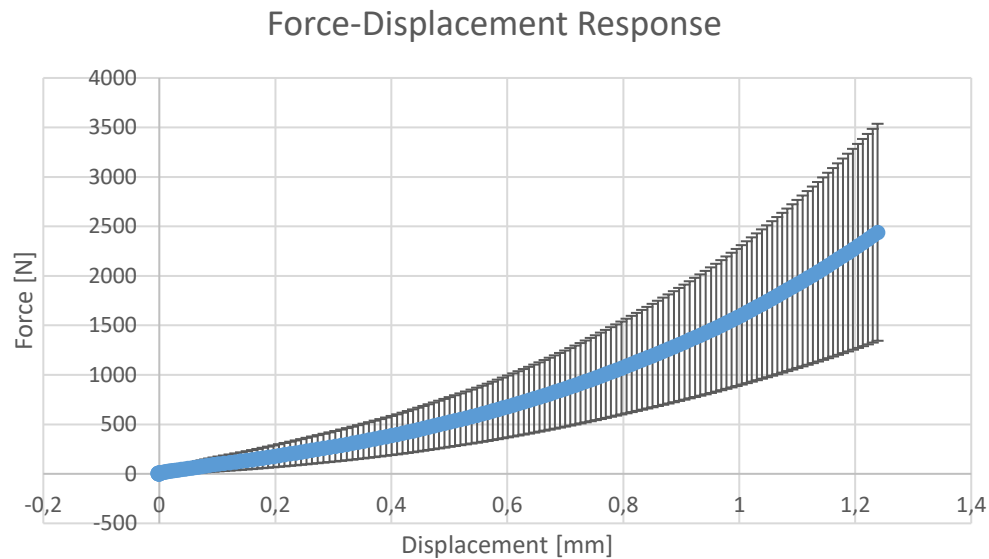
### 4.2.2 Corridors

For the purpose of validating a HBM against the above mentioned loading condition, a response corridors is necessary ([Figure 3](#)). This corridor is constructed of the average response of the IVD experiments plus and minus the standard deviation of these experiments, evaluated per timestep. These corridors were constructed omitting the responses from the L4-L5 experiments, as these experiments had a much shorter experimental time, which would have in turn truncated the corridors too severely.

#### 1. Force Displacement Response for the Experimental Data

Provided as an excel file: *corridors.xlsx*





**Figure 3** Corridor of the experimental test results

#### 4.2.3 Model validation

After extracting the simulation results, the model response can be compared to the given corridors presented in **Figure 3**. Simulation corridors can be constructed by running all lumbar spinal levels in the simulation setup and applying an average  $\pm$  standard deviation approach which was used to construct the experimental corridor. Alternatively each individual lumbar level can be compared with the corridor, using a corridor bases assessment approach.

## References

Newell, N. C. (2017). Strain Rate Dependence of Internal Pressure and External Bulge in Human Intervertebral Discs during Axial Compression. *IRCOBI Conference*, (pp. 670–671). Antwerp.