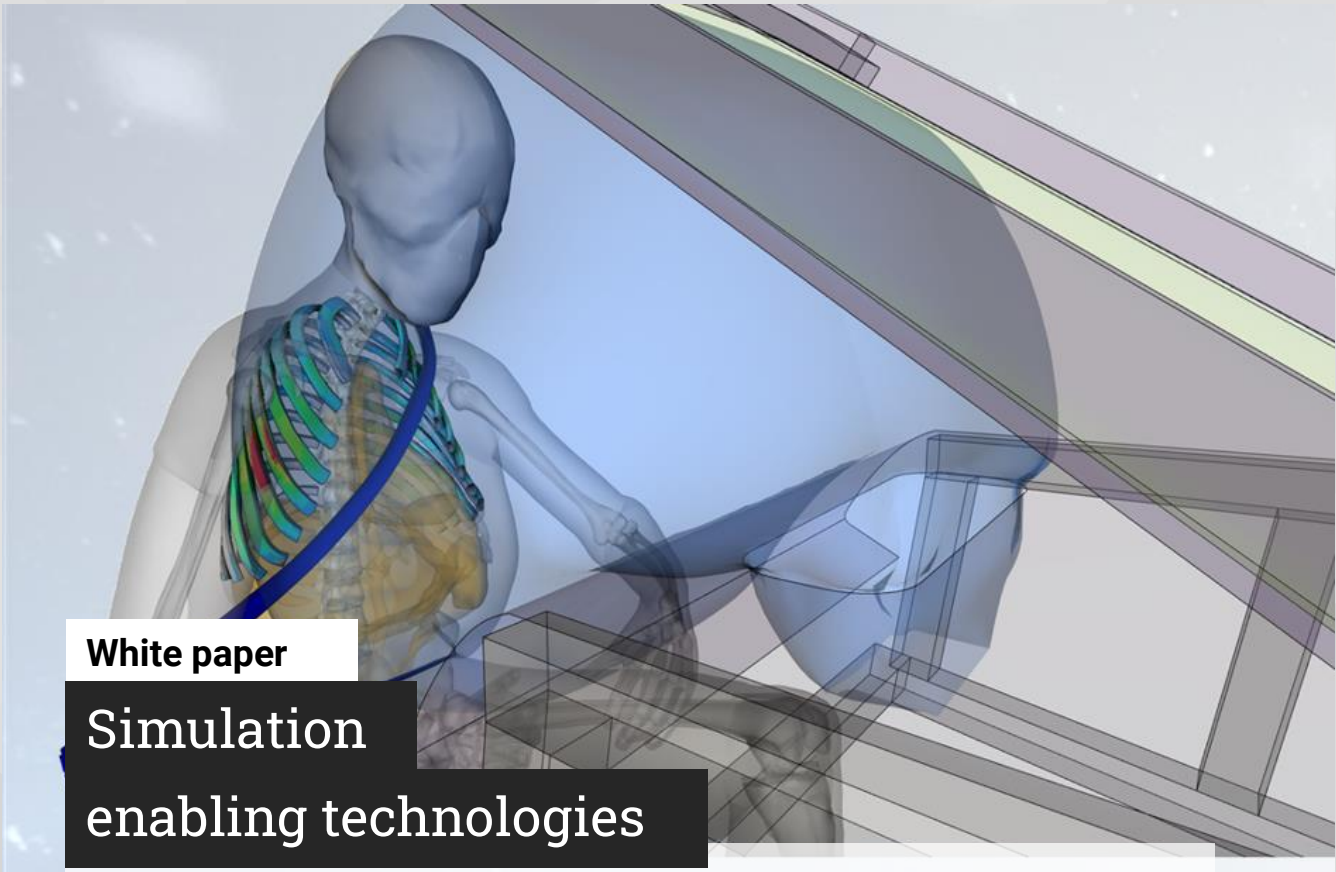
BETA
SIMULATION SOLUTIONS

physics on screen



White paper

Simulation enabling technologies

Engineering simulation tools for HBM analyses

An increasing amount of Human Body Models (HBMs) is currently available to assess occupant and Vulnerable Road User (VRU) safety. Yet, these are only available in a limited number of postures and body types. This white paper describes the BETA CAE systems software suite pre- and post- processing tools for the creation of unlimited HBM postures and BMIs along with a tool for the creation of bike variants for VRU safety studies.

Introduction

Recent advances in occupant safety have greatly reduced the risk of injuries for road users. However, motor vehicle crashes remain one of the leading causes of death. Computational models of the human body have been used to assess occupant and other Vulnerable Road Users' (VRU) safety for more than 50 years, spreading from Anthropometric Device models to the more recent and sophisticated Human Body Models (HBMs). Yet, the FE tools utilizing these new models have not yet caught up with these advances making their use difficult and time-consuming.
Most of the available HBMs are provided in only a seated and a standing nominal position. This limits their scope of applications unless time-consuming pre-processing techniques are implemented to articulate them in the required position. Apart from the high computational cost that this approach demands, it often leads to inaccurate or non-biofidelic results.

Furthermore, despite obesity being a key factor in the injury risk of motorized vehicle occupants, current crash tests are conducted mainly on dummies that represent midsize or larger young men and small young women.

Bicycle accidents also capture a significant percentage of the total number of road accident fatalities and modern cars are required to embody features that prevent and mitigate cyclists' injuries. However, for such analyses FE packages have not yet caught up to the required level.

In this white paper, an array of tools developed by BETA CAE Systems to address the aforementioned topics is presented. These tools are:

- The ANSA HBM articulation tool, for accurate and real-time positioning and articulation of all currently available HBMs.
- The ANSA HBM variants tool, for the creation of a wide range of BMIs for each occupant.
- The ANSA Bike configurator tool for the generation of vulnerable road user tests including a wide range of different bikes.
- The HBM post processing tool for the calculation of injury criteria and for reporting the different body regions' kinematics.

The HBM Articulation Tool

ANSA's HBM Articulation tool is developed to fulfil the need for accurate, real-time positioning and articulation of all currently available HBMs through a user-friendly interface within ANSA. The tool combines state-of-the-art morphing techniques along with a Multi-Body Dynamics solver developed by BETA CAE Systems.

Supported HBMs

ANSA supports most commonly used HBM models (and their hierarchy tree) in the market, including GHBMC, THUMS, SAFER and VIVA+. Rigorous software development and verification tests ensure that every ANSA release is up to date with the latest HBM versions and variants (eg M50,95 F05 etc). For each HBM, a set of metadata is provided as the basis for the functionality of the HBMs Articulation tool.

HBM Positioning

ANSA's HBM Articulation Tool allows engineers to position the HBM in space and manipulate its limps in a fast and easy way. The movements can be implemented either interactively by using the mouse or by numerical values input. Graphical information on the screen provides the user important data for the completion of tasks, such as the limb's axis of rotation, stop angles, current angle of rotation etc.

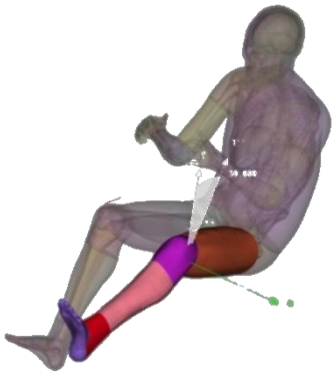


Figure 1: Graphical information

Since the dummy is a model validated by its supplier, the user may not wish to export it from a pre-processor. ANSA provides the option to input the model as an ordinary include file. After the positioning process is completed, the final position of the nodes can be output as a separate include for future use.

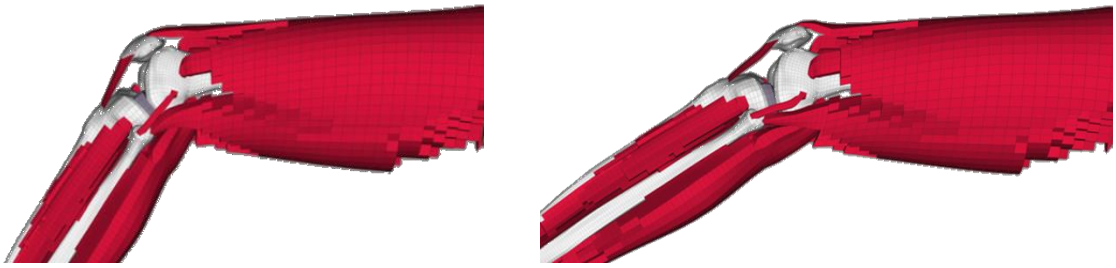


Figure 2: Knee Extension

High Level of Biofidelity

The tool is developed to attain high levels of biofidelity, by incorporating anthropometric studies and measurements. Great focus is placed on the articulation of the cervical spine up to the level of every individual vertebra, knee and patella flexion and extension, shoulder and abduction and adduction, and wrist pronation and supination.

Figure 3: Neck Extension

The tool allows the user to perform movements in such detail as in finger flexion/extension for gripping actions holding a steering wheel.

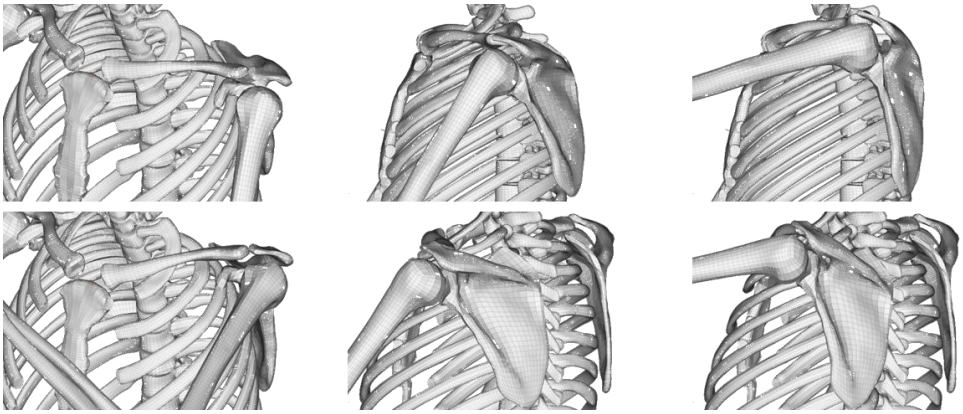


Figure 4: Shoulder Extension from three different angles.(Front, Side, Back)

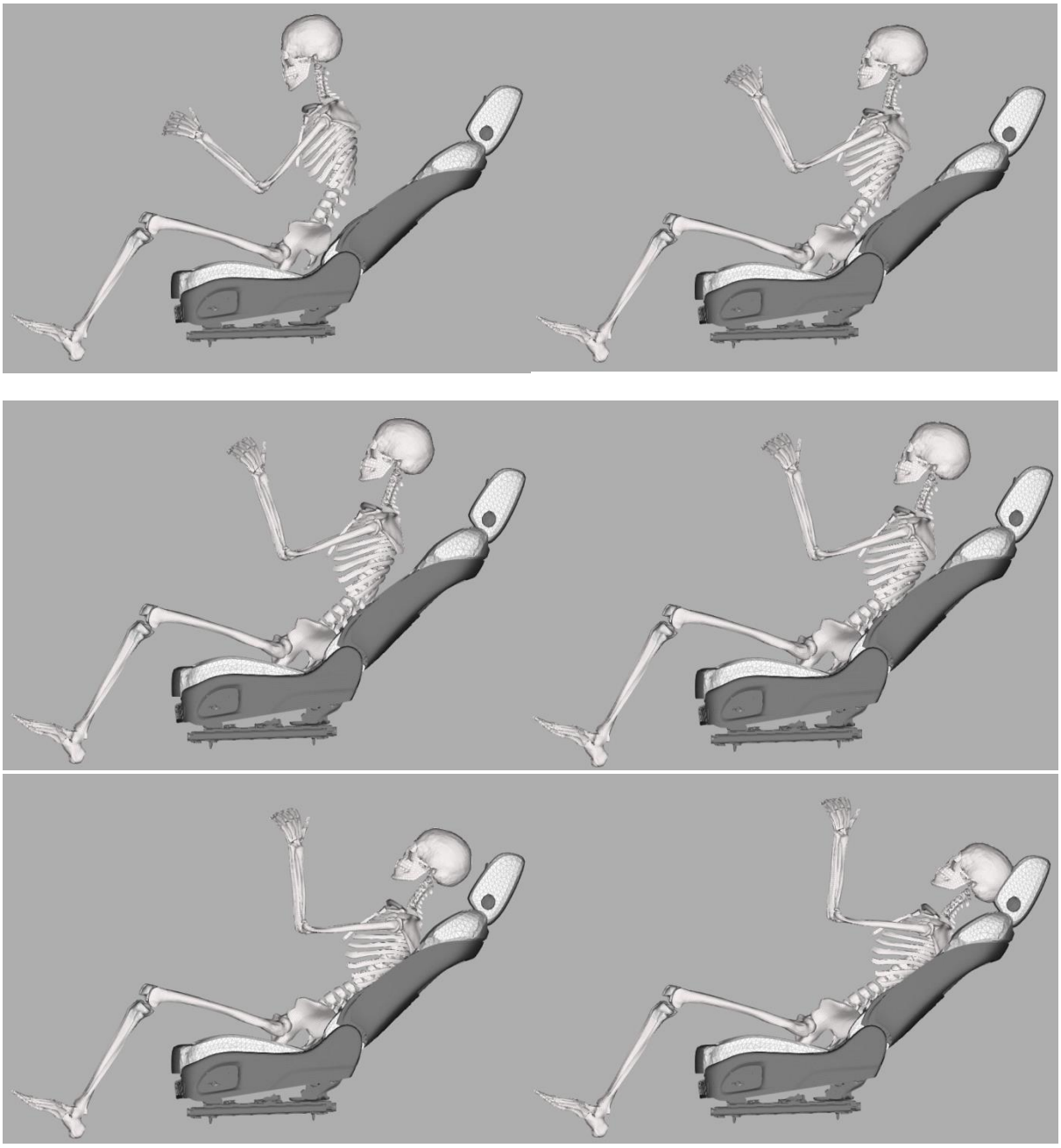


Figure 5: occupant's Pelvic-Lumbar and Cervical extension on a reclined car seat.

The HBM Variants Tool

The HBM Variants tool of ANSA is developed to fulfill the need for a wider range of BMIs for the different HBMs currently available in the market. Through a user-friendly interface within ANSA, the tool combines state-of-the-art morphing and meshing techniques to create HBM Variants without the requirement of any prior knowledge of these techniques.

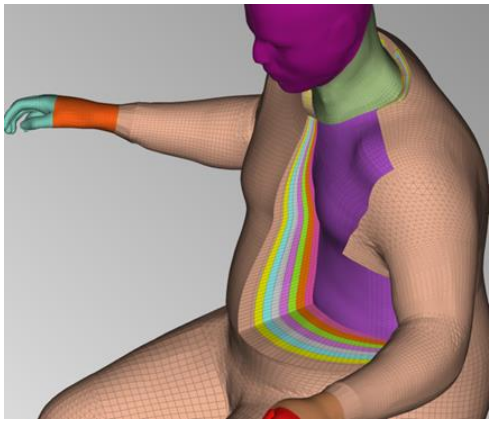


Figure 6: . Cross-section of subcutaneous fat for different BMIs. Each coloured layer corresponds to a different BMI

Supported HBMs

Rigorous software development and verification tests ensure that every ANSA release is up to date with the latest HBM versions starting with GHBMC M50. For each HBM, a set of metadata required to ensure the functionality of the HBMs Variants tool, is provided by the tool.

HBM Variants

ANSA's HBM Variants Tool allows engineers to quickly create a wide variety of BMIs for each HBM. The tool not only considers the increase in subcutaneous fat but also the respective increase of internal organs' volume.

The required BMI is created by simply filling in the required value in the respective field of the tool's window while all meshing and morphing actions are performed automatically in the background until the variant is ready.

Again, ANSA provides the option to input the model as an ordinary include file. After the variants' creation process is completed, the newly created layers of fat, along with the final position of the nodes on the morphed organs can be output as separate includes for future use.

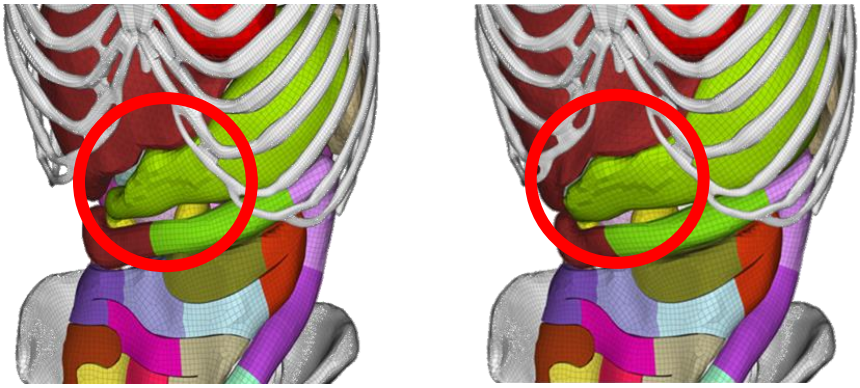


Figure 7: Front side of resized to BMI organs inside the rib cage. Left: Reference, Right: Morphed

High Level of Biofidelity

The tool has been developed to attain high levels of biofidelity. For the sizing of the internal organs insights have been obtained from anthropometric studies and measurements from research on cancer treatment, diabetes, and other chronic conditions.

Each BMI is linked to a respective volume of the kidneys, liver, gallbladder, stomach, and pancreas while stomach's greater and lesser curvatures are also taken into account.
The target outer body surface created is based on 3D scans from real cases to achieve the maximum accuracy and biofidelity of the outcome.

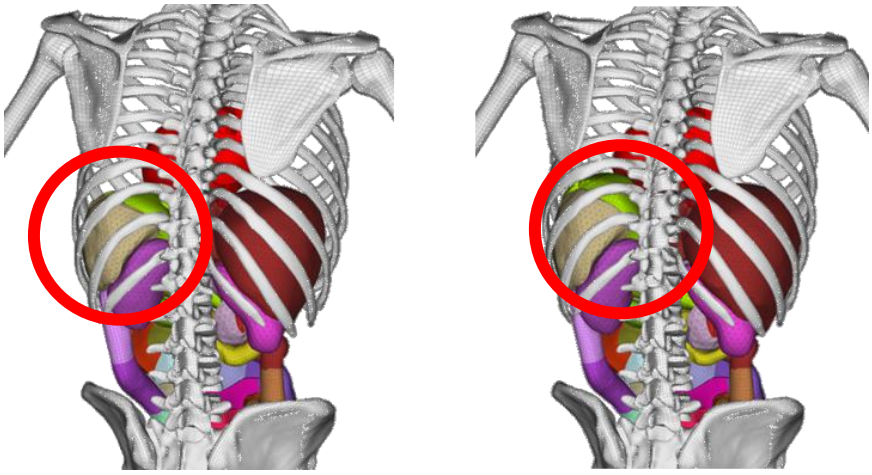


Figure 8: Back side of resized to BMI organs inside the rib cage. Left: Reference, Right: Morphed

The Bike Configurator Tool

The Bike Configurator Tool of ANSA has been developed to facilitate the rapid creation of several bike variants through a user-friendly interface. The tool combines state-of-the-art morphing techniques and requires no prior knowledge for its use.

Supported Types and Variants

The tool allows the near real-time modification of a reference city bike meshed model. A wide range of configurations is supported, in terms of stack and reach distance, seat height and crank's degrees of rotation.

Figure 9: Positioning of THUMS on configurations via combining HBM Articulation tool and Bike Configurator Tool

To make the model as realistic as possible, while keeping the level of detail such that computational time is not increased during a solution, significant care has been placed on the detail of the different parts that compose the reference geometry. Such incorporated parts include the bike's forks, drive train crank, chain sprocket, frame rear hub bracket etc.

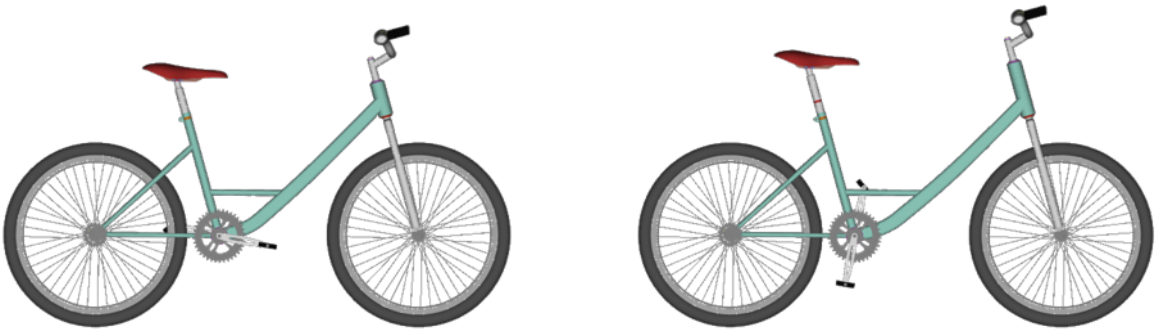


Figure 10: Two different configurations with elongated stack and reach length, seat height and 90 degrees of crank rotation

The tool is developed considering the most up-to-date accident reconstruction studies and takes into account numerous factors that influence a rider's injury severity during an accident.
The user can choose between three predefined size configurations (S, M, L) of a reference geometry and a further customized process for creating variants through direct per parameter numerical input according to the project's specifications.
A user-friendly overview of the parameters is provided through a 2D sketch of the bike in the tool's GUI.

Great Range of Sizes

The tool covers the easy creation of a great range of sizes, indicative of those currently available in the market.
The supported configurations are designed to fit most body types of both male and female riders, for ages spreading from adolescents up to elderly people. Its compatibility with the HBM and Dummy Articulation tools of ANSA, allows for the positioning of all supported HBMs and ATDs on the configuration of interest for accident reconstruction studies, virtual certification processes, sizing studies etc.

The HBM Post Tool

META post processor's HBM Post tool, provides the capability to quickly create reports for the whole HBM or for different regions of the body. Running interactively or in batch mode, META can create PowerPoint and PDF reports including videos and images of the kinematics, strain contour plots, elements erosion identification, and injury criteria calculations for GHBM, SAFER and THUMS models.

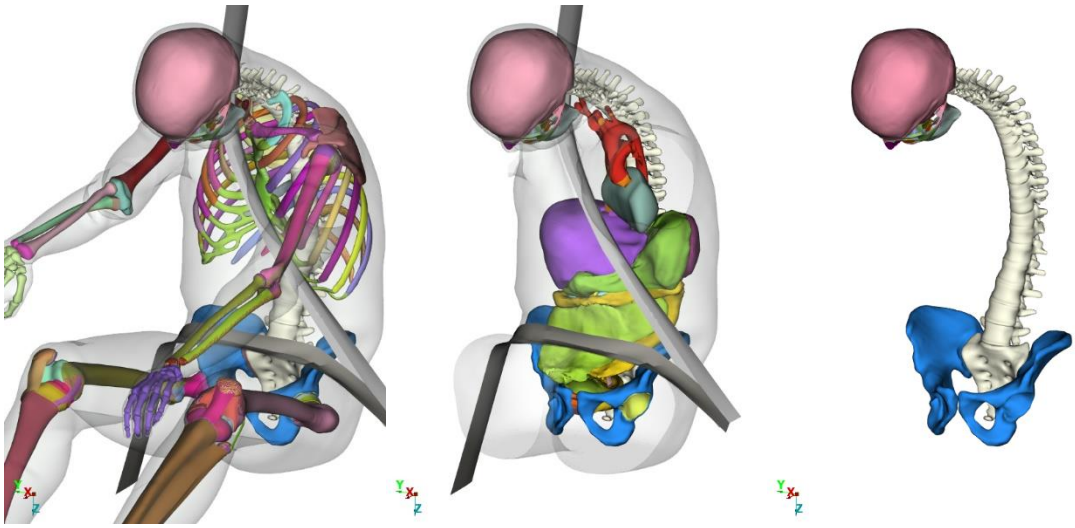


Figure 10: Kinematics report

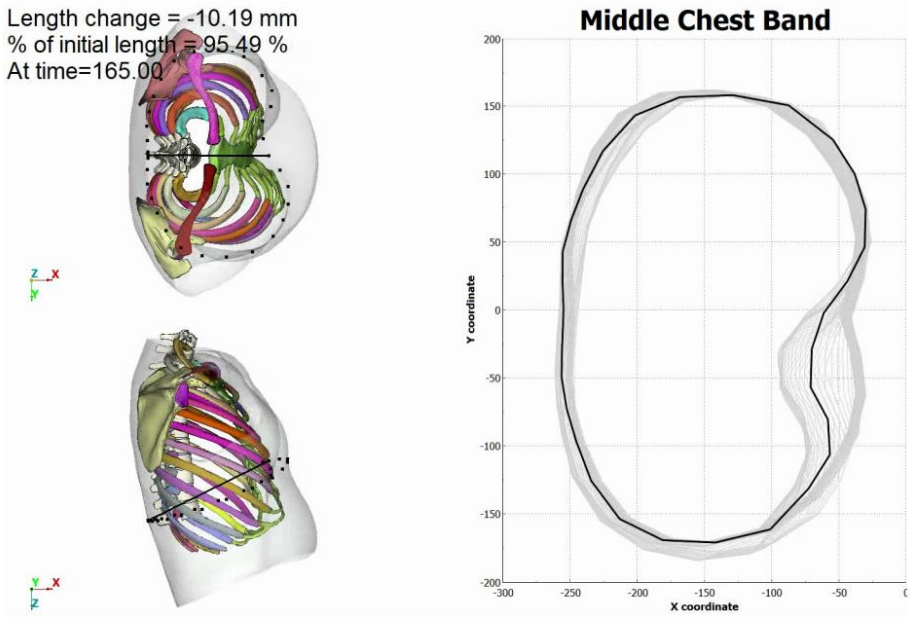


Figure 11: Chest bands deformations in report

Injury Criteria

Brain Cumulative Strain Damage Measure (CSDM) is calculated for GHBM and THUMS models. The tool provides the option to calculate the contribution of each part of the brain to the total CSDM result, as well as the individual CSDM result of each part. The Brain Major Principal Strains are reported and the 100th, 99th, 95th and 50th percentile values and elements are identified. For the SAFER HBM, the Concussion Risk (mTBI) is calculated according to *Fahlstedt M, Meng S, Kleiven S. 2022. Influence of Strain Post-Processing on Brain Injury Prediction*, using the 99th percentile value.

THUMS_AM50_wAirbag_wStrains: Brain CSDM

Metric Name	Value
MPS Threshold	0.25
Injured Volume	74685 mm^3
Total Volume	1452736 mm^3
CSDM	**0.0514**

Brain Parts Contribution		
Part Name	PID	CSDM
White_Matter_Cerebrum_R	88000100	0.0129
Gray_Matter_Cerebrum_R	88000101	0.0085
White_Matter_Cerebellum_R	88000102	0.0000
Gray_Matter_Cerebellum_R	88000103	0.0000
White_Matter_Stem_R	88000104	0.0000
Gray_Matter_Stem_R	88000105	0.0000
White_Matter_Cerebrum_L	88000120	0.0112
Gray_Matter_Cerebrum_L	88000121	0.0095
White_Matter_Cerebellum_L	88000122	0.0000
Gray_Matter_Cerebellum_L	88000123	0.0000

* Brain parts contribution = part injured volume / brain total volume

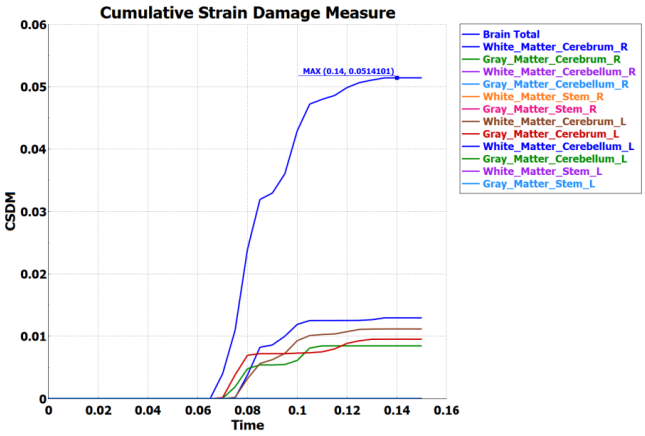
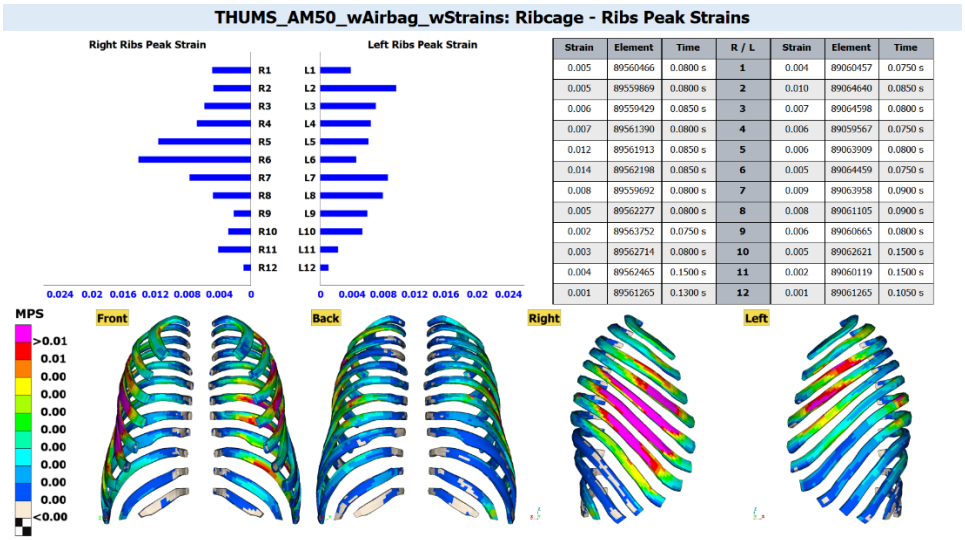


Figure 12: Brain CSDM and Brain's parts contribution in the total CSDM result

Regarding the ribcage, the probability of fracture is calculated for each rib according to:

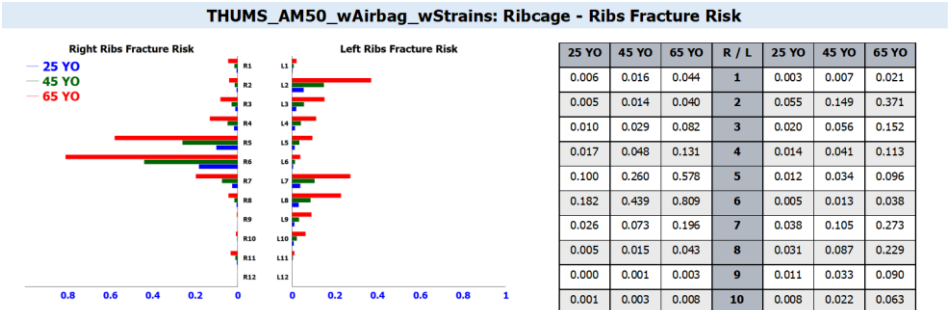
Karl-Johan Larsson, Amanda Blennow, Johan Iraeus, Bengt Pipkorn and Nils Lubbe. 2021. Rib Cortical Bone Fracture Risk as a Function of Age and Rib Strain: Updated Injury Prediction Using Finite Element Human Body Models.

The Rib fracture probability is calculated by default for 25, 45 and 65 years of age, or for any other selected age. The parameters of the Weibull or the Log-normal distribution can be also adjusted.



Strain	Element	Time	R / L	Strain	Element	Time
0.005	89560466	0.0800 s	1	0.004	89060457	0.0750 s
0.005	89559869	0.0800 s	2	0.010	89064640	0.0850 s
0.006	89559429	0.0850 s	3	0.007	89064598	0.0800 s
0.007	89561390	0.0800 s	4	0.006	89059567	0.0750 s
0.012	89561913	0.0850 s	5	0.006	89063909	0.0800 s
0.014	89562198	0.0850 s	6	0.005	89064459	0.0750 s
0.008	89559692	0.0800 s	7	0.009	89063958	0.0900 s
0.005	89562277	0.0800 s	8	0.008	89061105	0.0900 s
0.002	89563752	0.0750 s	9	0.006	89060665	0.0800 s
0.003	89562714	0.0800 s	10	0.005	89062621	0.1500 s
0.004	89562465	0.1500 s	11	0.002	89060119	0.1500 s
0.001	89561265	0.1300 s	12	0.001	89061265	0.1050 s

Figure 13: Ribs Peak Strains



25 YO	45 YO	65 YO	R / L	25 YO	45 YO	65 YO
0.006	0.016	0.044	1	0.003	0.007	0.021
0.005	0.014	0.040	2	0.055	0.149	0.371
0.010	0.029	0.082	3	0.020	0.056	0.152
0.017	0.048	0.131	4	0.014	0.041	0.113
0.100	0.260	0.578	5	0.012	0.034	0.096
0.182	0.439	0.809	6	0.005	0.013	0.038
0.026	0.073	0.196	7	0.038	0.105	0.273
0.005	0.015	0.043	8	0.031	0.087	0.229
0.000	0.001	0.003	9	0.011	0.033	0.090
0.001	0.003	0.008	10	0.008	0.022	0.063
0.004	0.012	0.033	11	0.001	0.004	0.011
0.000	0.000	0.000	12	0.000	0.000	0.000

Fracture risk in % at AGES:	25	45	65
2+	10.18	24.18	46.51
3+	5.19	15.02	34.28
4+	2.81	10.41	26.08
5+	1.43	7.78	20.39

Jason Forman, Shubham Kulkarni, Daniel Perez-Rapela, Sayak Mukherjee, Matthew Panzer, Jason Kaltman. 2022. A Method for Thoracic Injury Risk Function Development for Human Body Models

Figure 14: Ribs fracture probability for the ages of 25, 45 and 65 years old

The Strain Energy Density (SED) criterion is calculated for the soft tissue abdominal organs (Liver, Spleen, Kidneys).

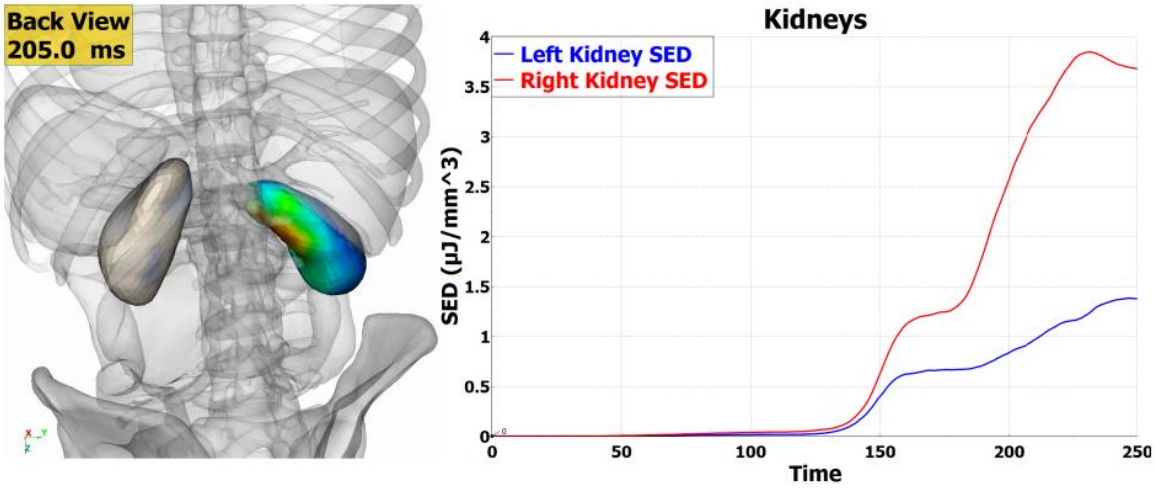


Figure 15: Kidneys SED report

Conclusion

A series of tools to address the increasing need for incorporating biofidelic models of the human body into safety, kinematics and other studies, as the industry moves towards virtual certification processes. The presented tools are robust in such a level that they can be used in all fields that conduct FE studies on the human body. They incorporate most recent anthropometric studies and findings from medical research and allow for:

- the accurate, real-time positioning and articulation of an HBM
- the creation of a wide range of BMIs of a reference HBM
- the generation of a wide range of bikes for vulnerable road user tests safety and kinematic assessment studies
- the easy and fast post processing of HBM results

About BETA CAE Systems International AG

BETA is a simulation solutions provider, dedicated to the development of state of the art software systems for CAE. For more than 30 years, we have been developing tools and delivering services for the front-runners in numerous sectors by listening to their needs and taking up even the most demanding challenges. For more information on BETA CAE systems, our products, and our services, visit www.beta-cae.com

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