



EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education



NEW TECHNOLOGIES
RESEARCH CENTRE
UNIVERSITY
OF WEST BOHEMIA

VIRTUAL HUMAN MODEL FOR ASSESSMENT OF FUTURE MOBILITY SAFETY

Jan Vychytil

17.10.2019

2nd International Symposium on Future Mobility Safety Science and Technology
Pilsen, Czech Republic, Europe
17 – 18 October 2019

OUR INSTITUTION

▶ University of West Bohemia

- ▶ 2 000 employees prepares 12 000 students within 9 schools and 5 research centres
 - ▶ IT, engineering, science and technology
 - ▶ Education, art, economics, health care studies, humanities and law



▶ New Technologies – Research Centre

- ▶ Independent self-financed university institution since 2000
- ▶ International team counting over 130 researchers
- ▶ Strength and impact analysis, **biomechanics**, laser technology, material technology and analysis, CFD



MLT DEPARTMENT

► Department

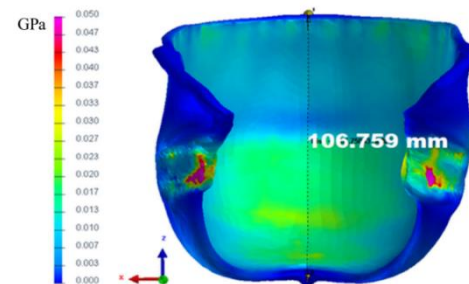
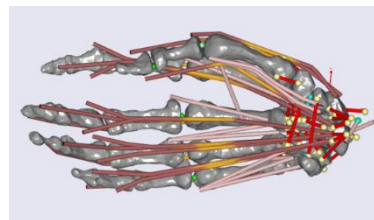
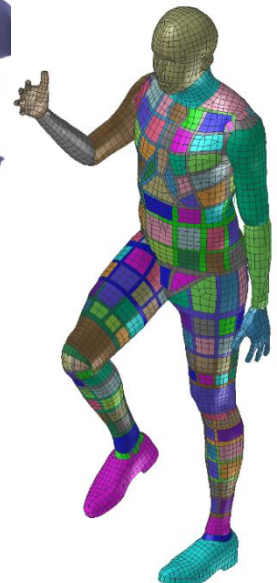
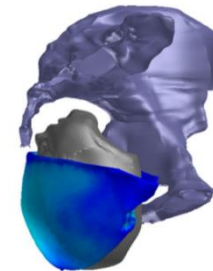
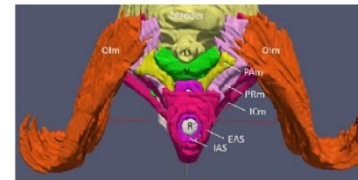
- Human Body Modelling

► Our team counts 14 + 1

- 1 Associated professor, 7 PostDocs,
2 PhD student, 1 Master degree,
3 Undergraduated student,
1 Administrator

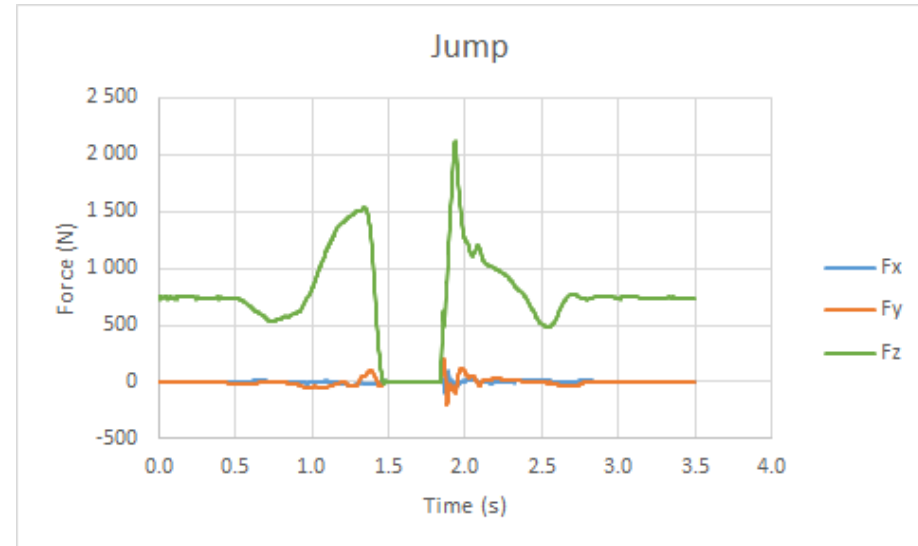
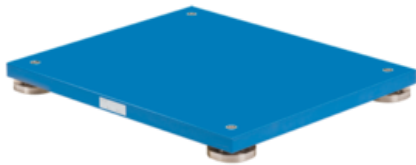
► Our focus

- Development of
human body models
- Applications (safety, medicine)

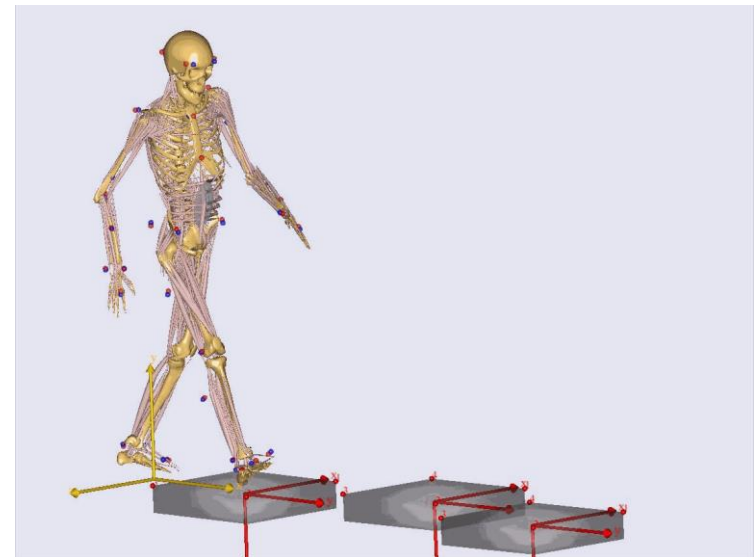


ANYBODY

- ▶ Musculoskeletal human body model
- ▶ AnyBody Modeling System
- ▶ [MoCap data](#)
- ▶ Reaction forces (Force plates)

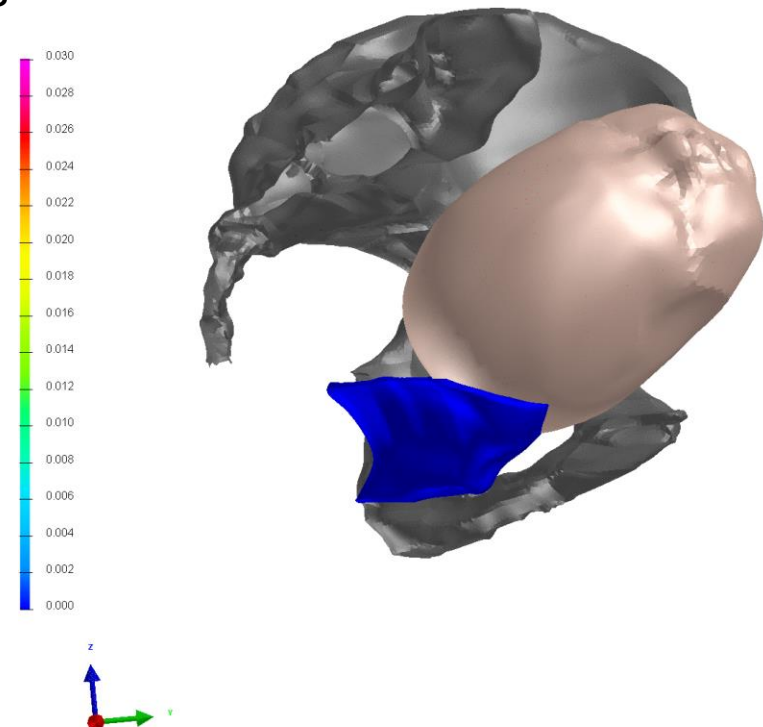


- ▶ **Output:** force distribution in muscles, activity, overloading, ...
- ▶ **Applications:** Ergonomy, sport, Clinical practice



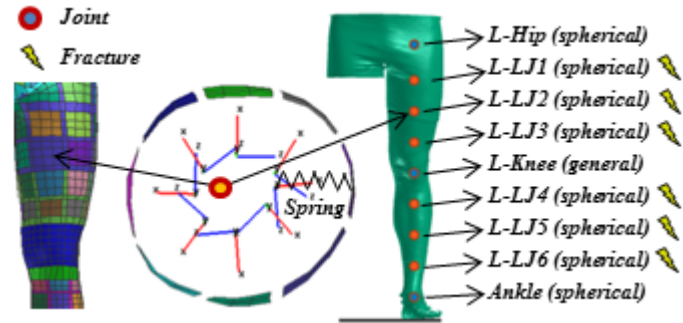
FE models of body parts

- Virtual Performance Solution software
- real anatomy based on MRI
- real passive biomechanical properties of tissues based on in-vitro measurements
- vaginal delivery simulation – clinical applications
 - stress distribution in pelvic muscles
 - effects of forceps use
 - process of manual perineal protection
- simulations of organ prolapse and pathologies

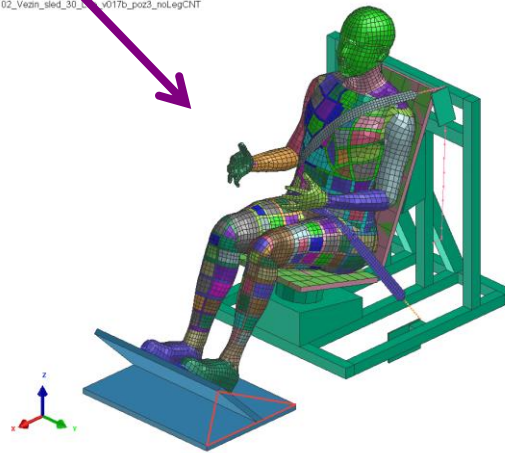


VIRTHUMAN

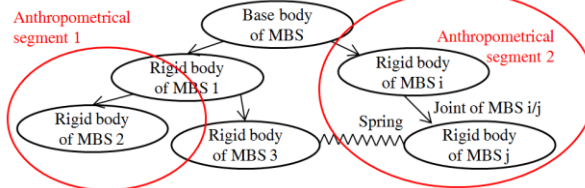
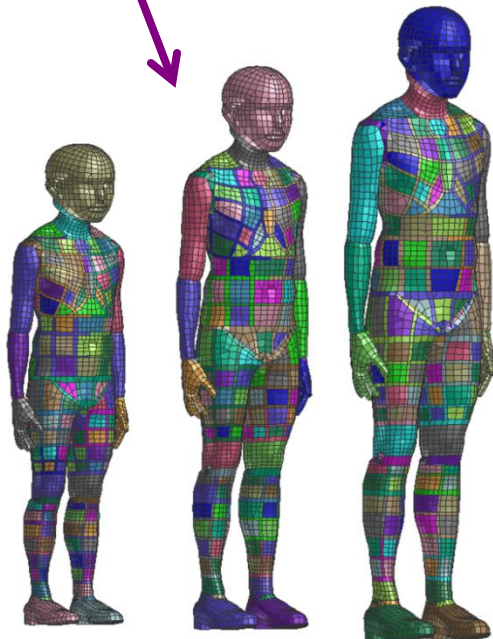
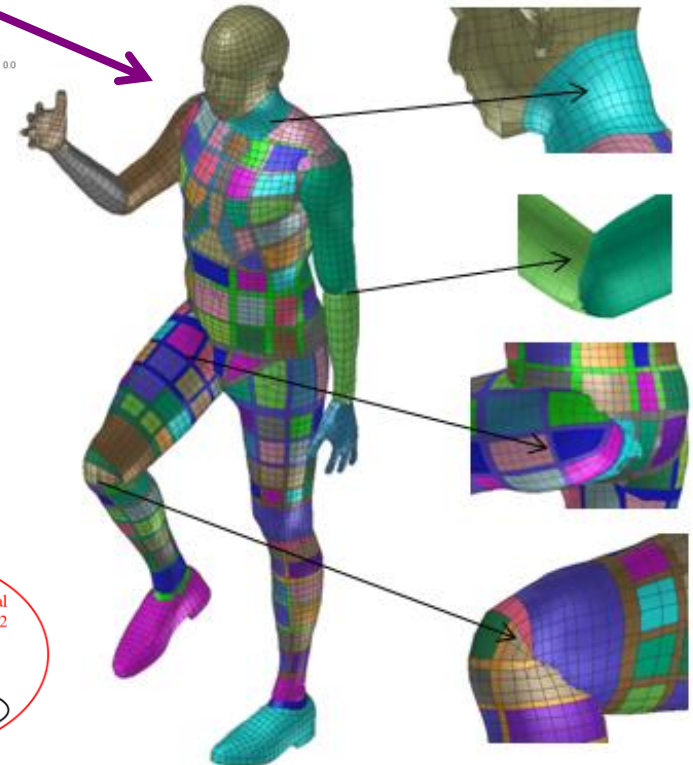
- ▶ MBS with compressible segments
- ▶ Simple positioning
- ▶ Multi-purpose validation
- ▶ Age scaling



02_Vein_sled_30...v017b_poz3_nolLegCNT



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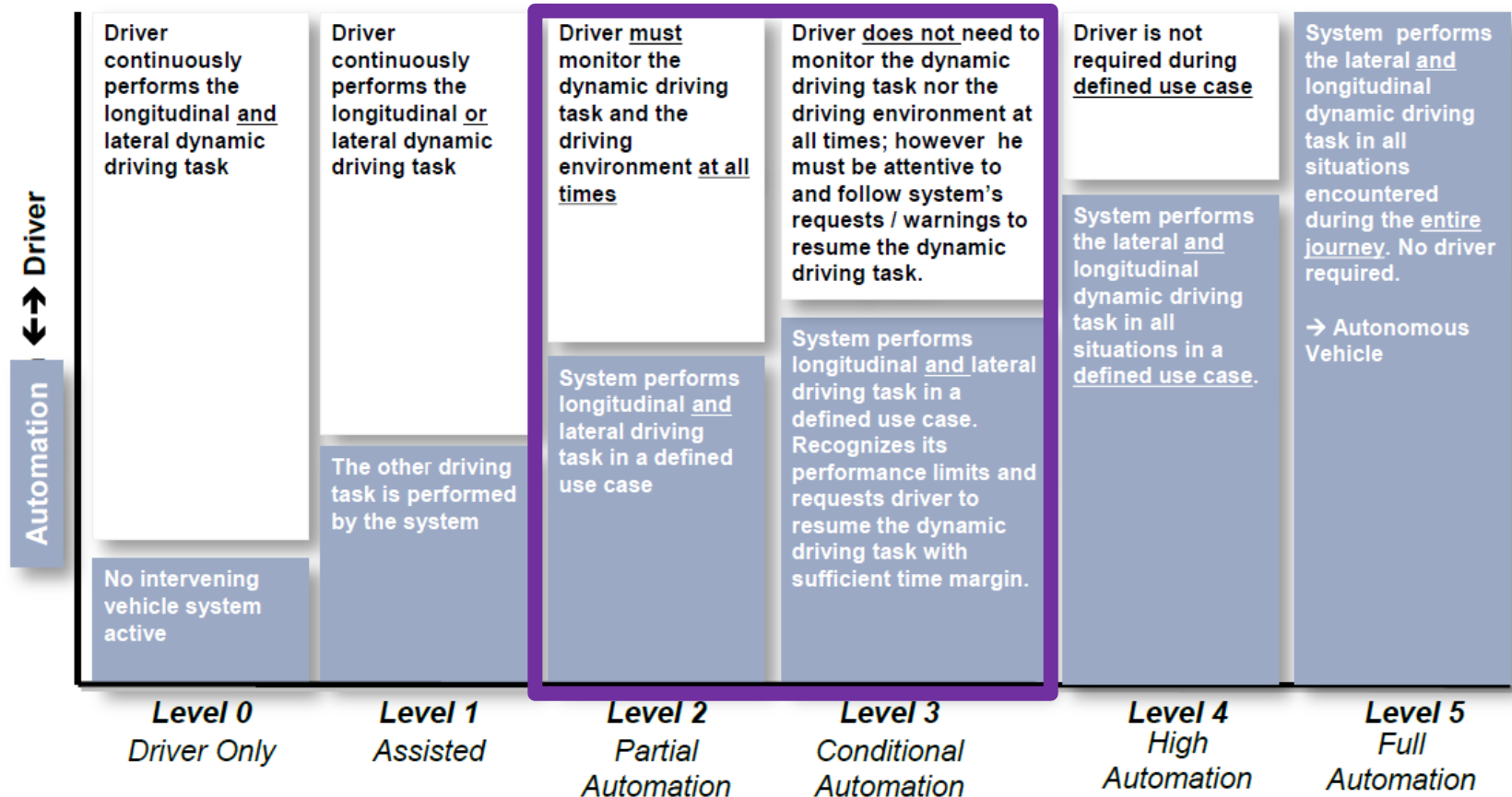
- Motivation
 - Future mobility (autonomous vehicles)
 - Physical tests & numerical simulations
- Virtual Human Model (Virthuman)
 - Structure
 - Scaling
 - Validation
 - Injury criteria evaluation
- Applications
 - Rollover
 - Ambulance impact
 - Non-standard seating



Levels of Automated Driving (Category C)

Document No. ITS/AD-04-14
(4th ITS/AD, 15 June 2015, agenda item 3-2)

Updated from WP29-162-20 (March 2014)

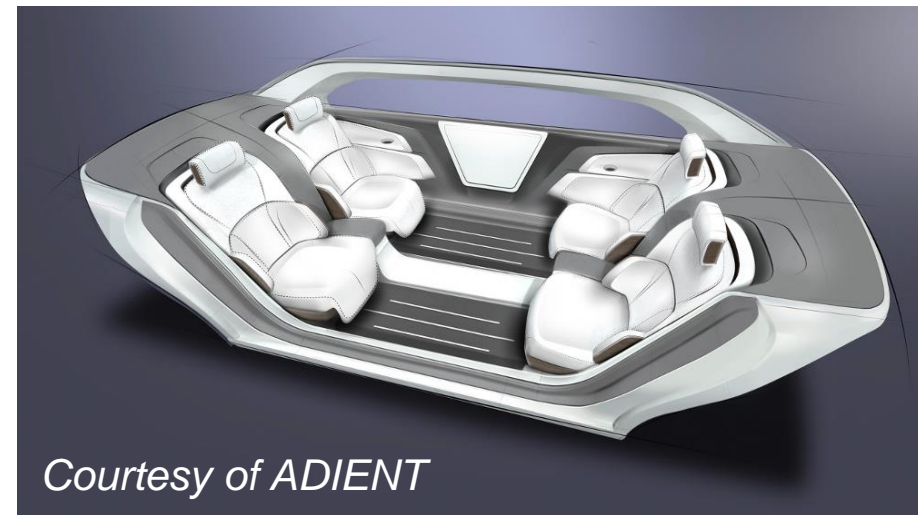


Level of automation* →

*terms acc. to SAE J3016

Future mobility

- ▶ Multi-modal transport (autonomous cars, two-wheelers)
- ▶ Complex passenger configurations
(„non-standardized“ seating)
- ▶ Multi-directional impacts
- ▶ Diverse population
- ▶ Virtual prototyping
- ▶ Design optimization
- ▶ Human protection
- ▶ Virtual approach to be addressed



Physical tests & numerical simulations

- Physical tests
 - Regulations
 - Consumer testing (EuroNCAP)
- Standard dummies
 - 5% female (1.510 m, 46.82 kg)
 - 50% male (1.751 m, 78.2 kg)
 - 95% male (1.873 m, 102.73 kg)
- Impact types
 - Frontal: Hybrid III family, THOR
 - Side: EuroSID, SID, SID-HIII, BioSID, WorldSID, ...
 - Rear: BioRID, RID2
 - Pedestrian: POLAR
 - Child: P0, P3/4, P3, P6, P10, Q-dummies, CRABI
- Injuries evaluation
 - Particular injury difficult to determine
 - Correlation of a function (acceleration, force) with injury likelihood



Physical tests & numerical simulations

Disadvantages

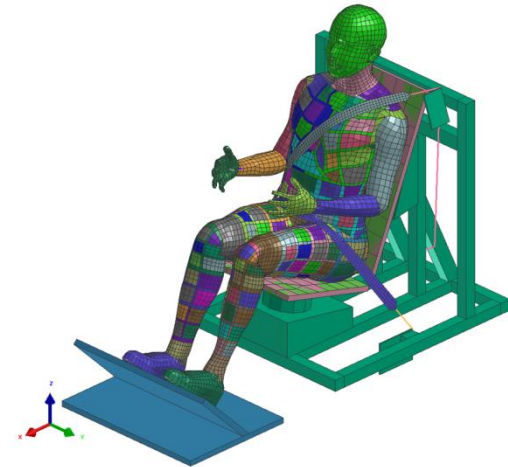
- Mechanical response
- Individuals far from 50%
- Single-purpose
- Standard seating positions
- Cost

Computer simulations

- Biofidelity
- Scaling
- Multi-purpose
- Cost



ens-newswire.com

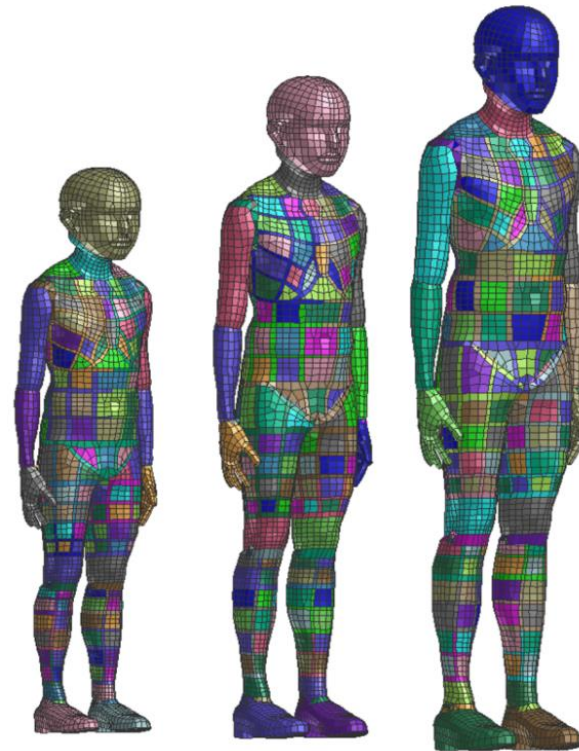


Support and supplement of experiments

- Consumer testing (active bonnets - EuroNCAP)
- Virtual prototyping
- Future mobility (nonstandard seating)

- Goals

- To prepare a scalable model of a human body for safety assessment
- To respect population diversity (sex, height, mass, age)
- Evaluation of injury criteria for general impact scenarios (cars, train interiors, public transportation, ...)



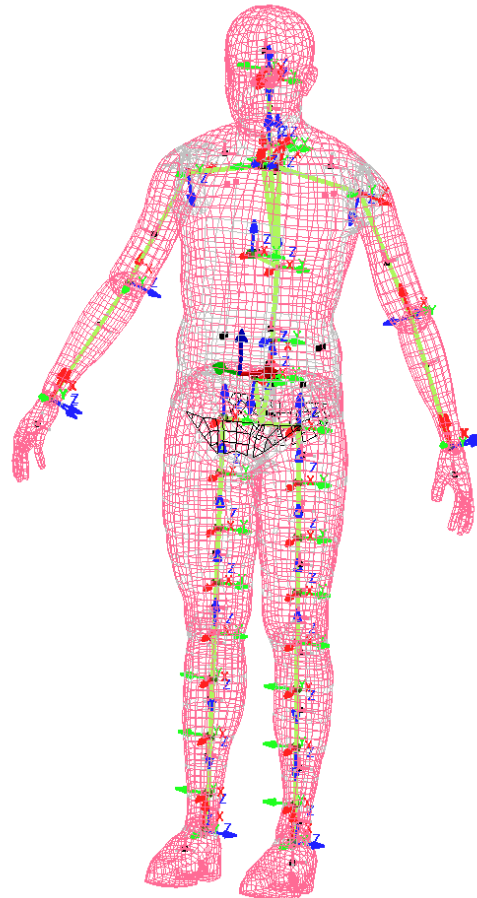
Virthuman - structure

Reference model proposal (50% male)

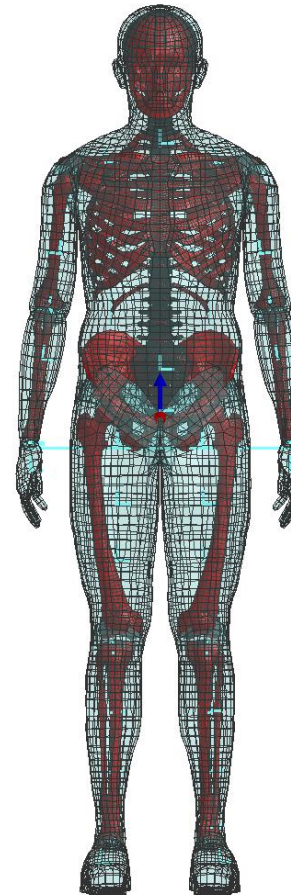
Scanned data from
CAESAR database



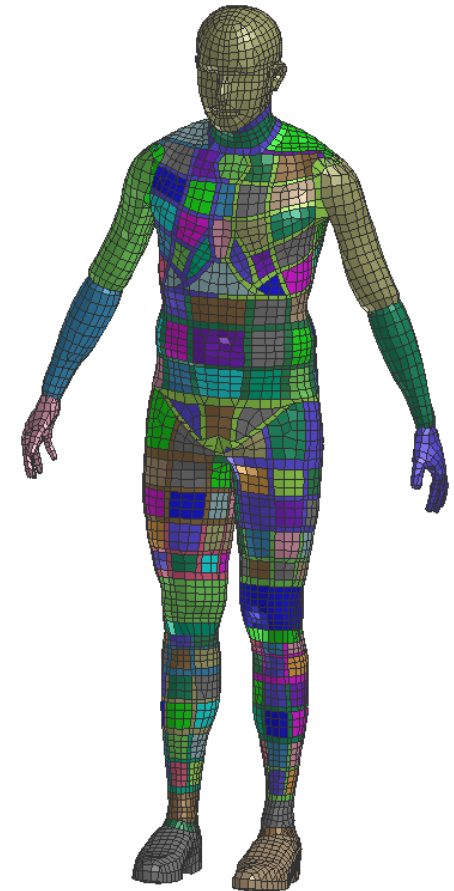
MBS basic
structure



Skin discretization
(local stiffness)



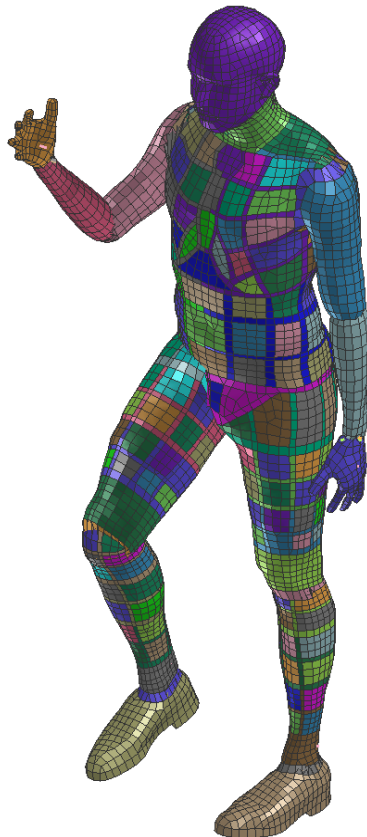
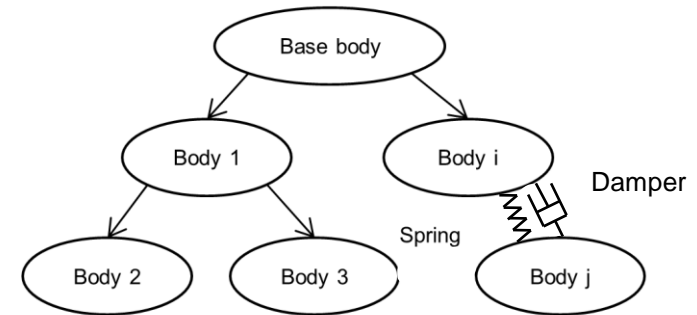
Completed model
(geometry)



Virthuman - structure

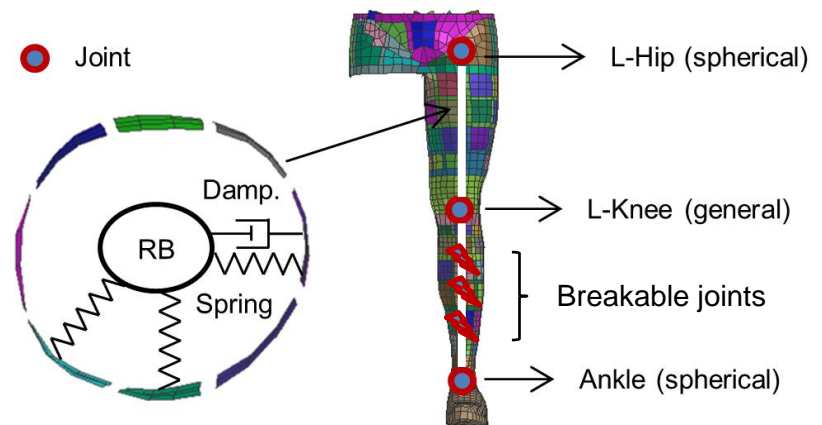
Basic MBS

- Body parts (upper, lower leg, foot, ...)
- Joints (hip, knee joint, ankle, ...)



Deformable segments

- Rigid elements connected with basic MBS via springs/dampers
- Body surface



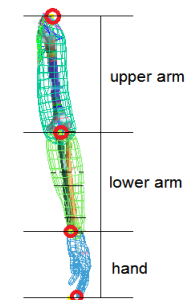
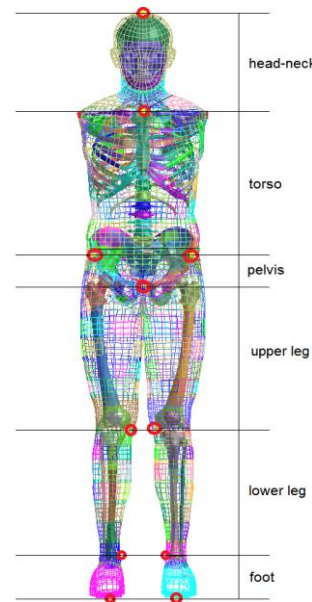
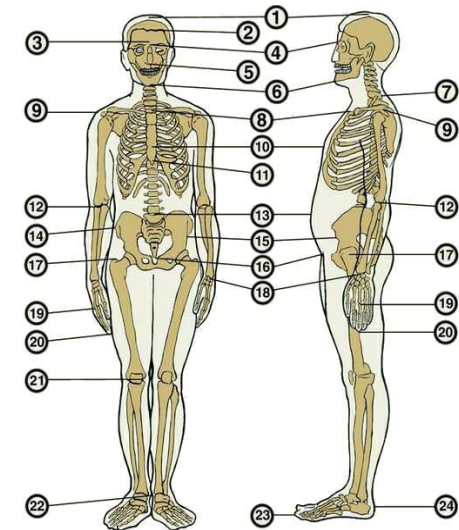
Virthuman - scaling

Scaling

- Anthropometric database
- Czech and Slovak population
- 5117 males, 5333 females, age 6 – 65 years
- Data collected in 1985

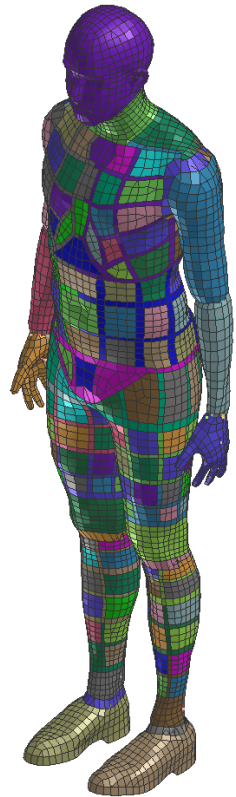


Anthropometric control points



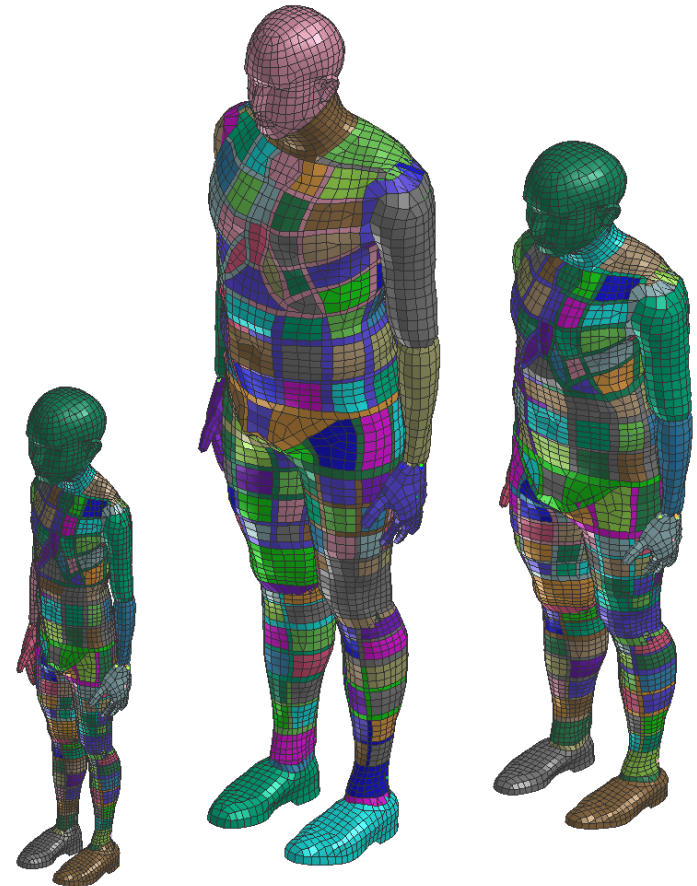
Segmentation for the model scaling

Virthuman - scaling



Male, 177 cm, 72 kg

scaling algorithm
→
sex, height, mass, age



6 years, male, 110 cm, 17 kg

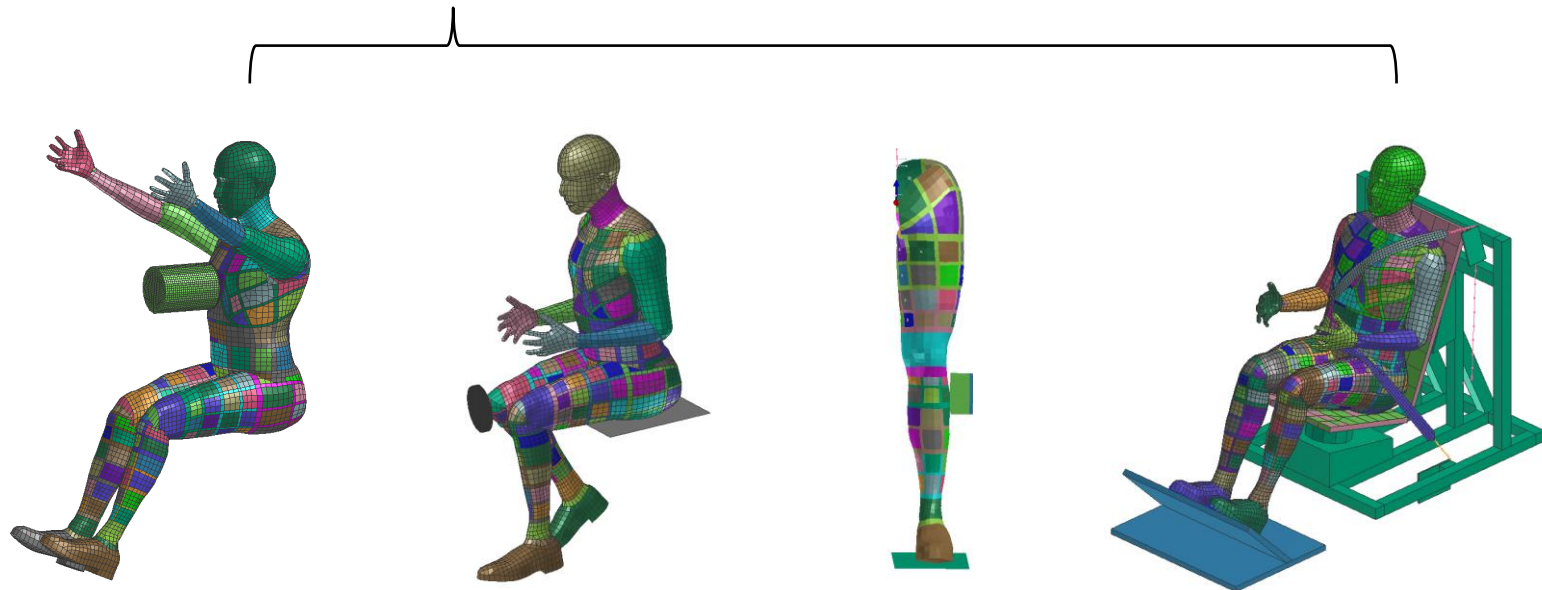
40 years, male, 190 cm, 104 kg

70 years, female, 150 cm, 90 kg

Virthuman - validation

Mechanical response

- Biofidelity
- Virtual human -> real human body
- Material parameters (stiffness, damping)
- Joints, springs and dampers representing tissues
- Validation tests



Virthuman - validation

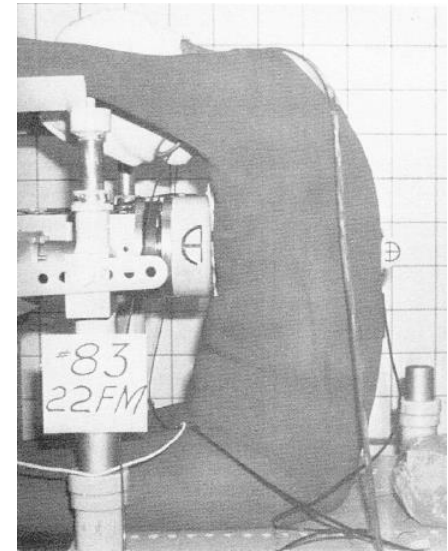
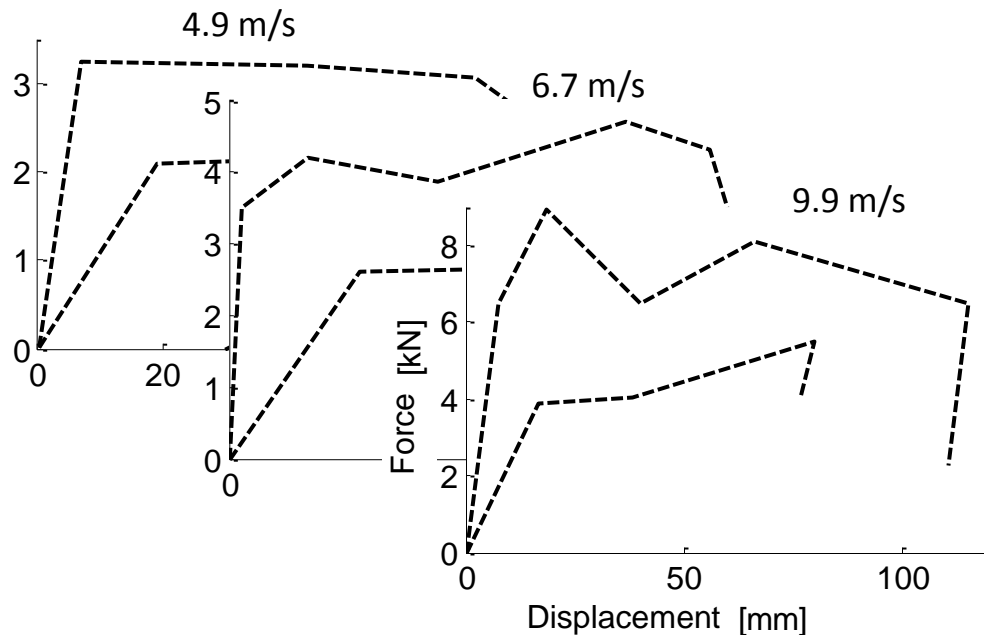
Validation tests

Segment	Impact direction	Impactor description	Impact velocity or g level
Head	Downwards	Sphere, 1.213 kg, Ø 96 mm	7.1 m/s
Neck	Frontal, lateral	-	15 g, 7 g
Shoulder	Lateral	Cylinder, 23.4 kg, Ø 150 mm	4.5 m/s
Thorax	Frontal	Cylinder, 23.4 kg, Ø 150 mm	4.9 m/s, 6.7 m/s, 9.9 m/s
	Lateral	Cylinder, 23.4 kg	4.3 m/s
	Lateral, Oblique	Cylinder, 23.97 kg	2.5 m/s
	Frontal	Belt, 22 kg and 76 kg	2.9 m/s, 7.8 m/s
Abdomen	Frontal	Bar, Ø 25 mm, 32 kg	6.1 m/s
		Belt	Force functions
Pelvis	Lateral	Plate, 23.4 kg, 100 x 200 mm	3.46 m/s, 6.66 m/s
Knee	Lateral (bending and shearing)	Block, 6.25 kg	5.56 m/s, 11.11 m/s
Femur	Frontal	Cylinder, 10.1 kg	13.2 m/s
Tibia	Lateral-medial	Bar, 32 kg	3.55 m/s
Fullscale	Sled test frontal	Sled	30 km/h
	Pedestrian lateral	Vehicle	40 km/h

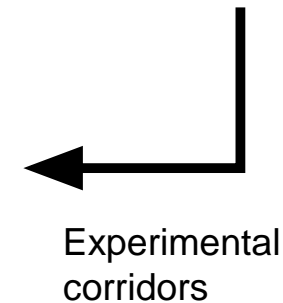
Virthuman - validation

- Thorax frontal

- Experiment with PMHS (Post Mortem Human Surrogates)
- Rigid cylinder as impactor, 23.4 kg, \varnothing 150 mm
- Frontal impact on sternum at 4.9 m/s, 6.7 m/s and 9.9 m/s
- Data ... contact force and the thorax deflection



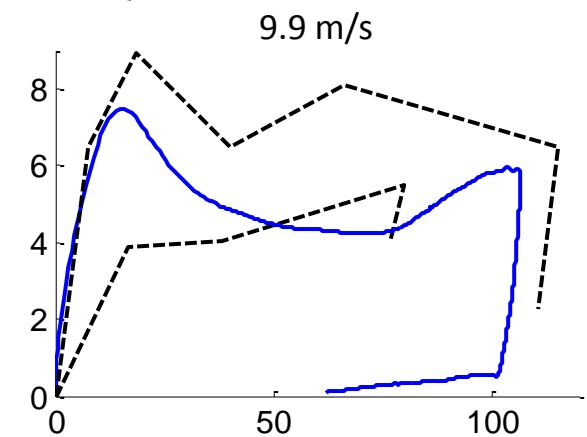
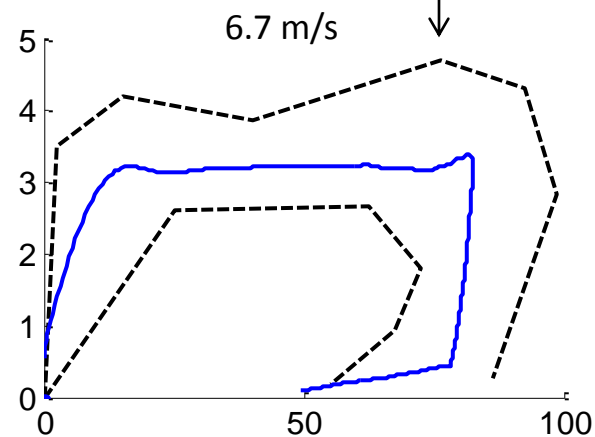
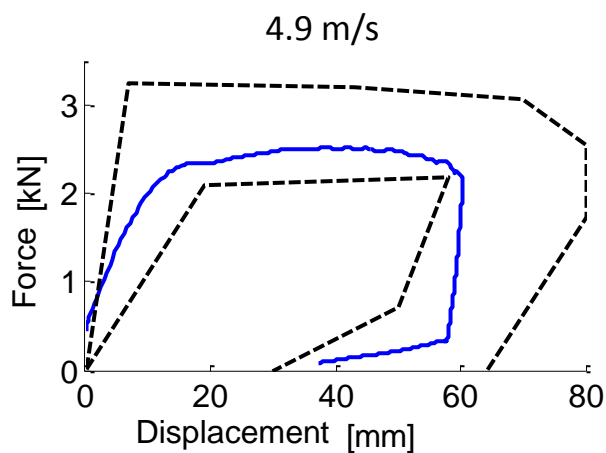
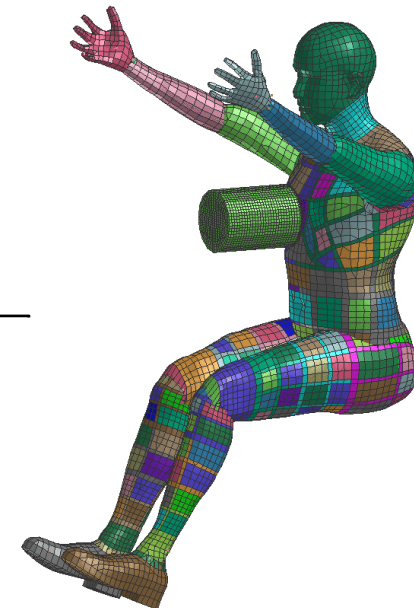
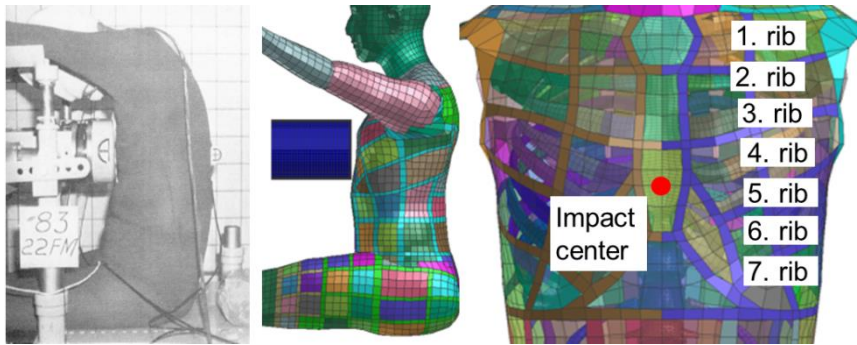
Kroell a kol., SAE 710851, 1970



Experimental corridors

Virthuman - validation

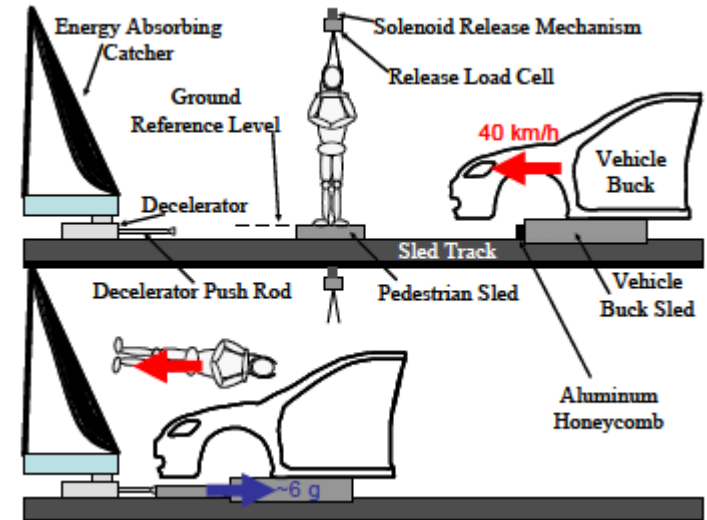
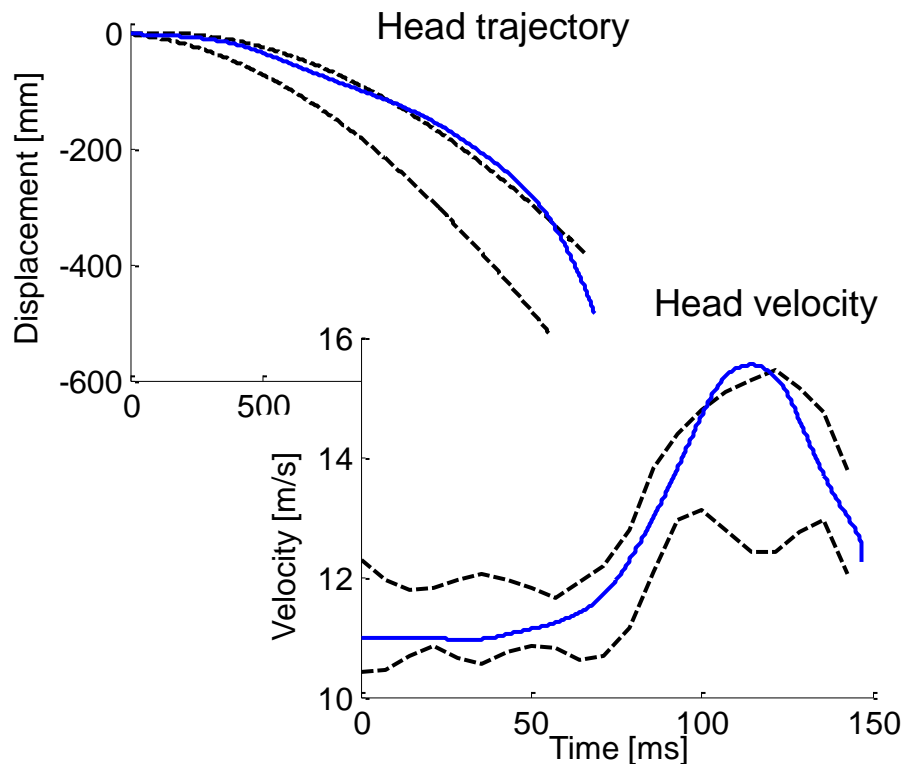
- Numerical simulation



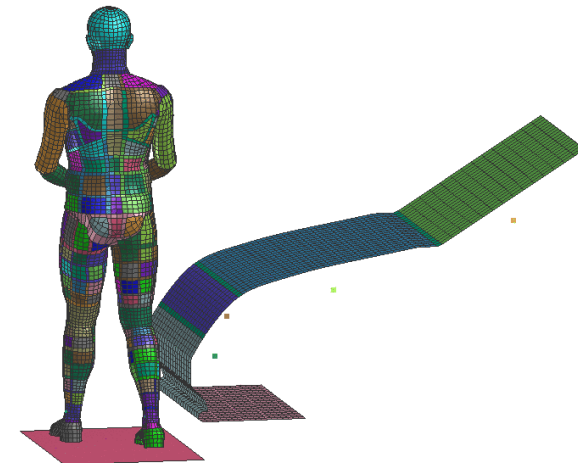
Virthuman - validation

- Pedestrian lateral

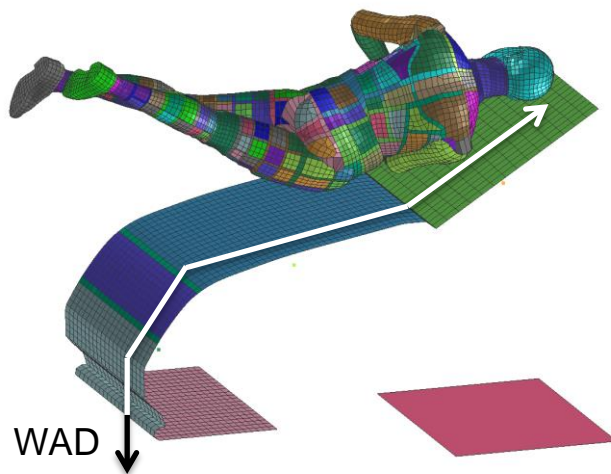
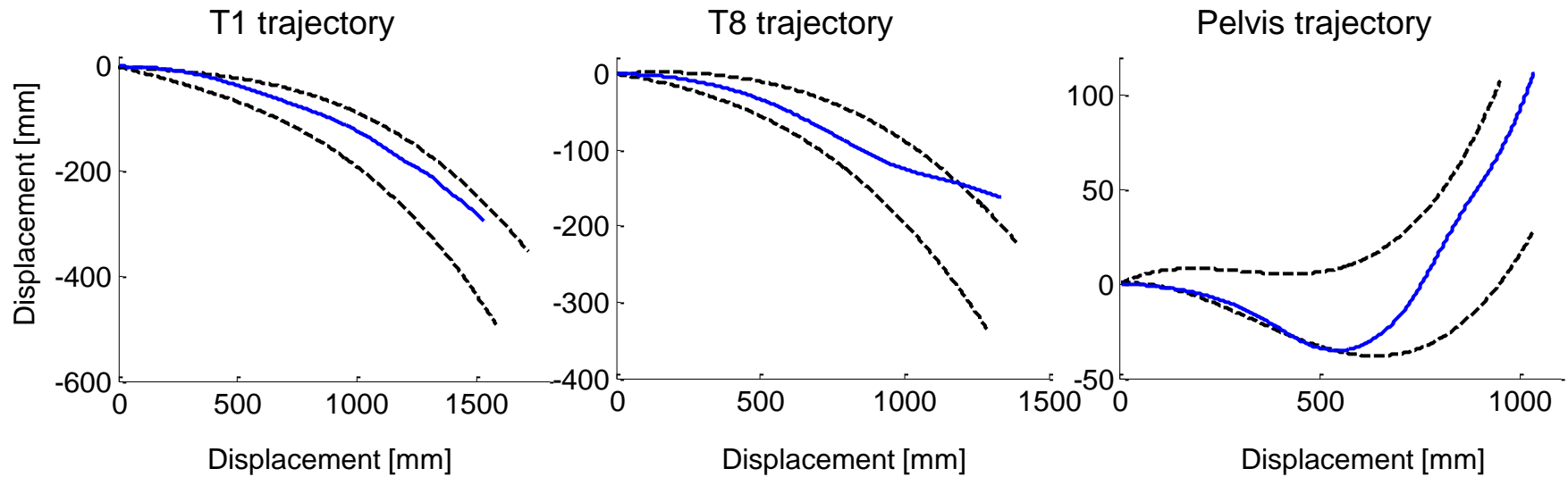
- Experiment with PMHS and POLAR-II dummies
- Small sedan, lateral impact at 40 km/h
- Velocity and trajectory of head, trajectories of T1, T8, and pelvis, WAD (Wrap Around Distance) and THS (Time of the Head Strike)



Kerrigan et al., Paper No. 05-0394, Univ. of Virginia (2005)



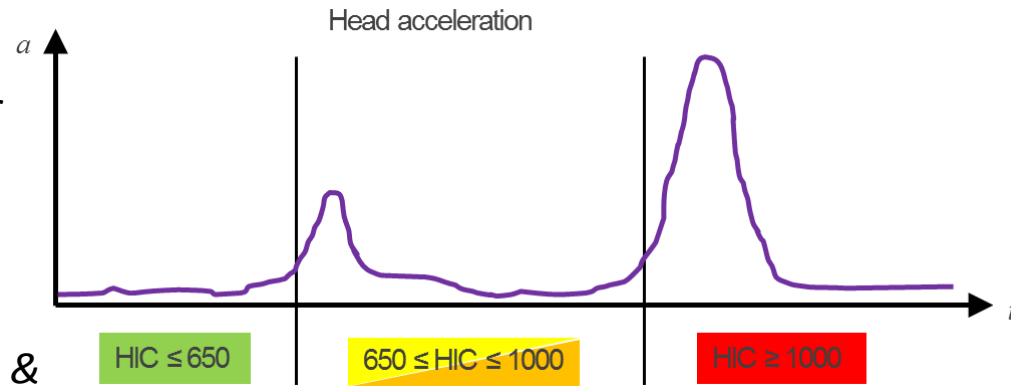
Virthuman - validation



	WAD [mm]	THS [ms]
PMHS	2310	145
VIRTHUMAN	2295	147
Polar-II	1947	128

• Injury criteria

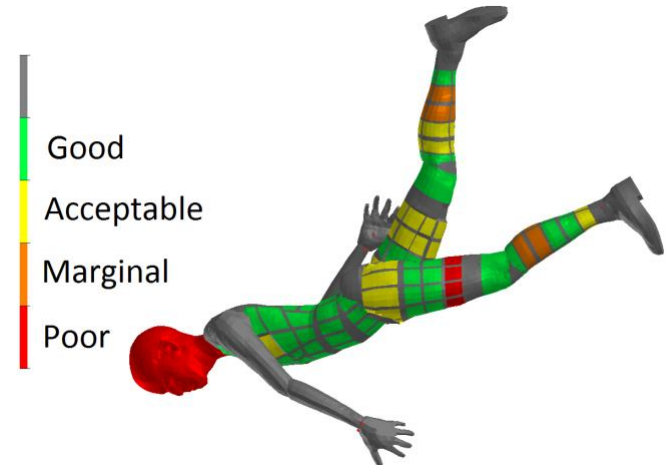
- **Head:** HIC
- **Neck:** Upper neck My, tension, shear
- **Thorax:** Front/side deflection, VC
- **Abdomen:** Compression force
- **Pelvis:** Pubic peak force
- **Legs:** Femur/tibia compression force & moment, knee moment



• Automatic algorithm

- Injury criteria evaluation for individual body parts
- Local coloring of the model depending on criterion value (injury severity)

Coloring based on EuroNCAP rating



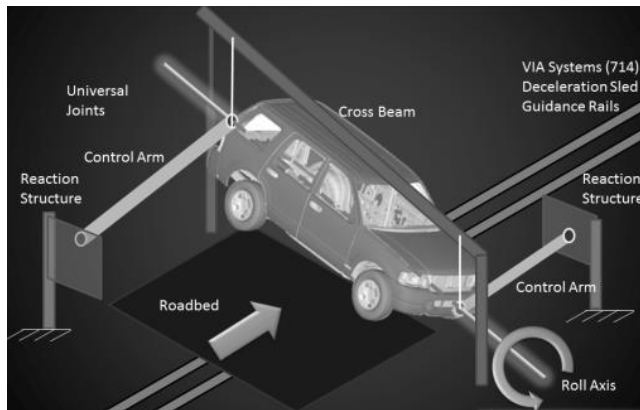
Applications - Rollover

- **Motivation**

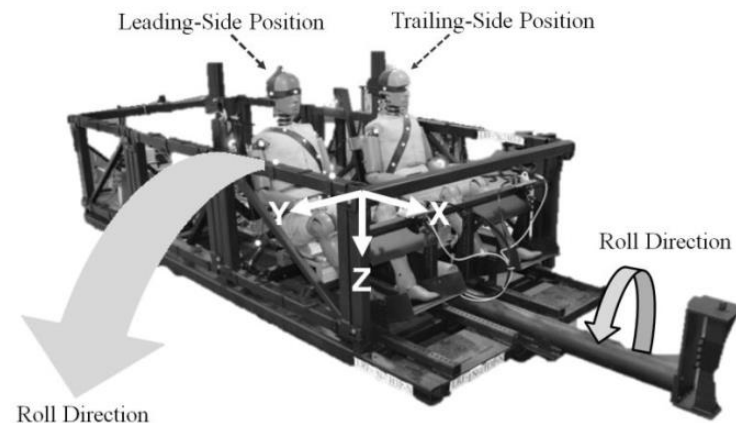
- *Vehicle occupant fatalities ... >33% crashes with rollover (since 2005)*
- *Complex impact scenario with multi-directional loading*
- *Example: [Breclav 16.2.2017](http://www.tn.cz) (source: www.tn.cz)*

- **Laboratory conditions**

- *Repeatability -> Dynamic Rollover Test System (DRoTS, University of Virginia)*
- *Vehicle buck -> mechanical response of dummies and PMHS*



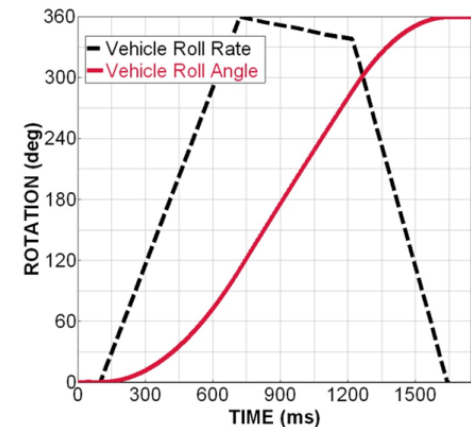
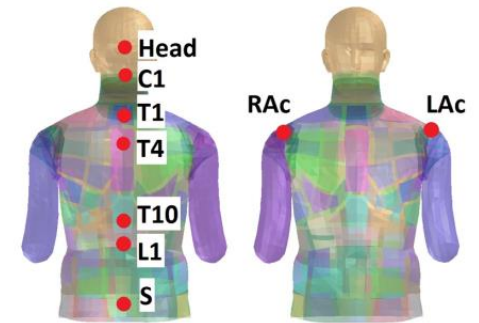
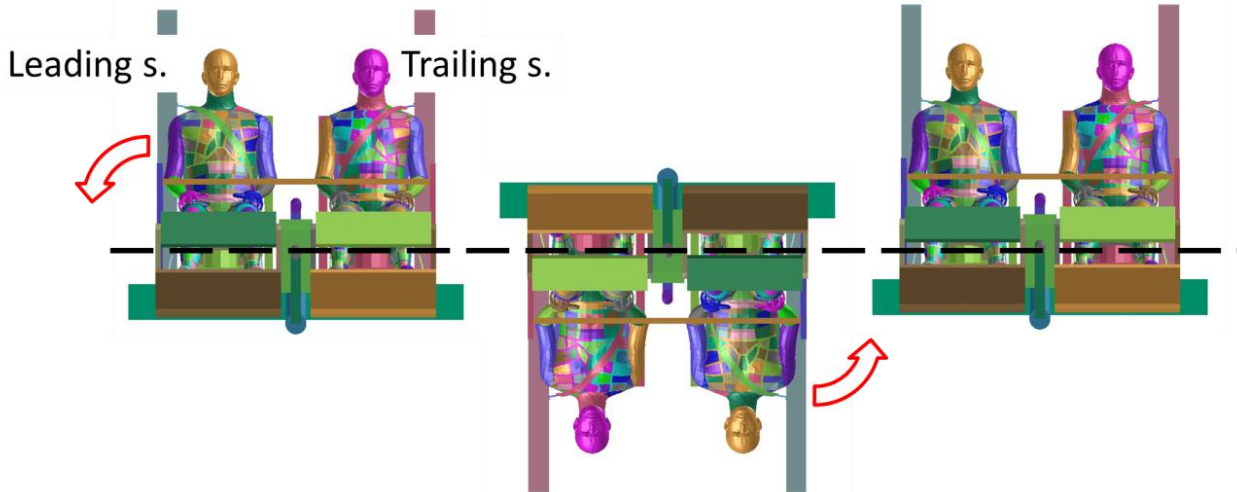
Source (both figures): Lessley et al., Stapp Car Crash J. 2014



Applications - Rollover

- **Goal**

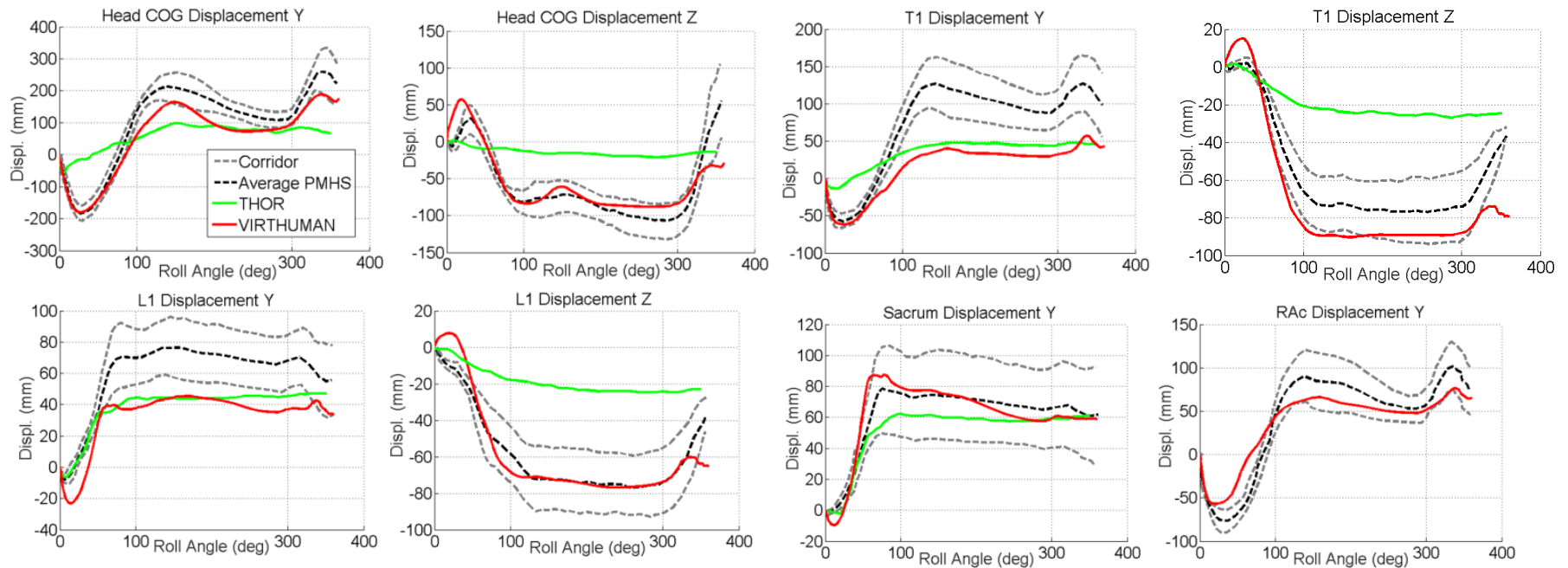
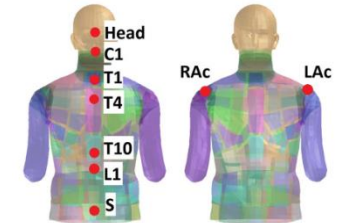
- *To confirm biofidelity of the Virthuman model in rollover scenario*
- *Vehicle buck in pure dynamic roll (360°)*
- *Scaled Virthuman (55YO, 81 kg, 180 cm)*
- *Trajectories of certain points*



Applications - Rollover

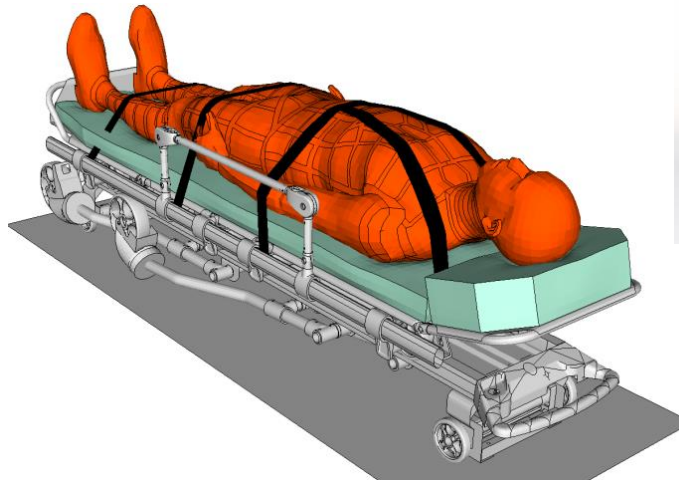
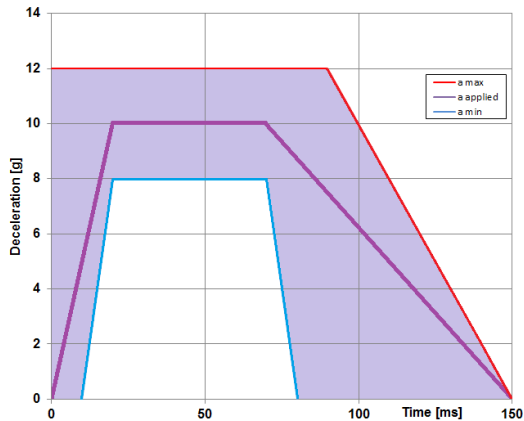
• Results

- Comparison of kinematics (PMHS, THOR dummy)
- [Video](#)



Applications – Ambulance impact

- **Goal**
 - *To investigate response of a trolley with stretcher*
 - *To test its performance in ambulance impact*
- **Model**
 - *Virthuman, 50th percentile male (Hybrid-III)*
 - *Deformable FE model of a trolley with stretcher*
- **Impact in 5 loading directions (coordinate axes)**
 - *Deceleration pulse DIN EN 1789*

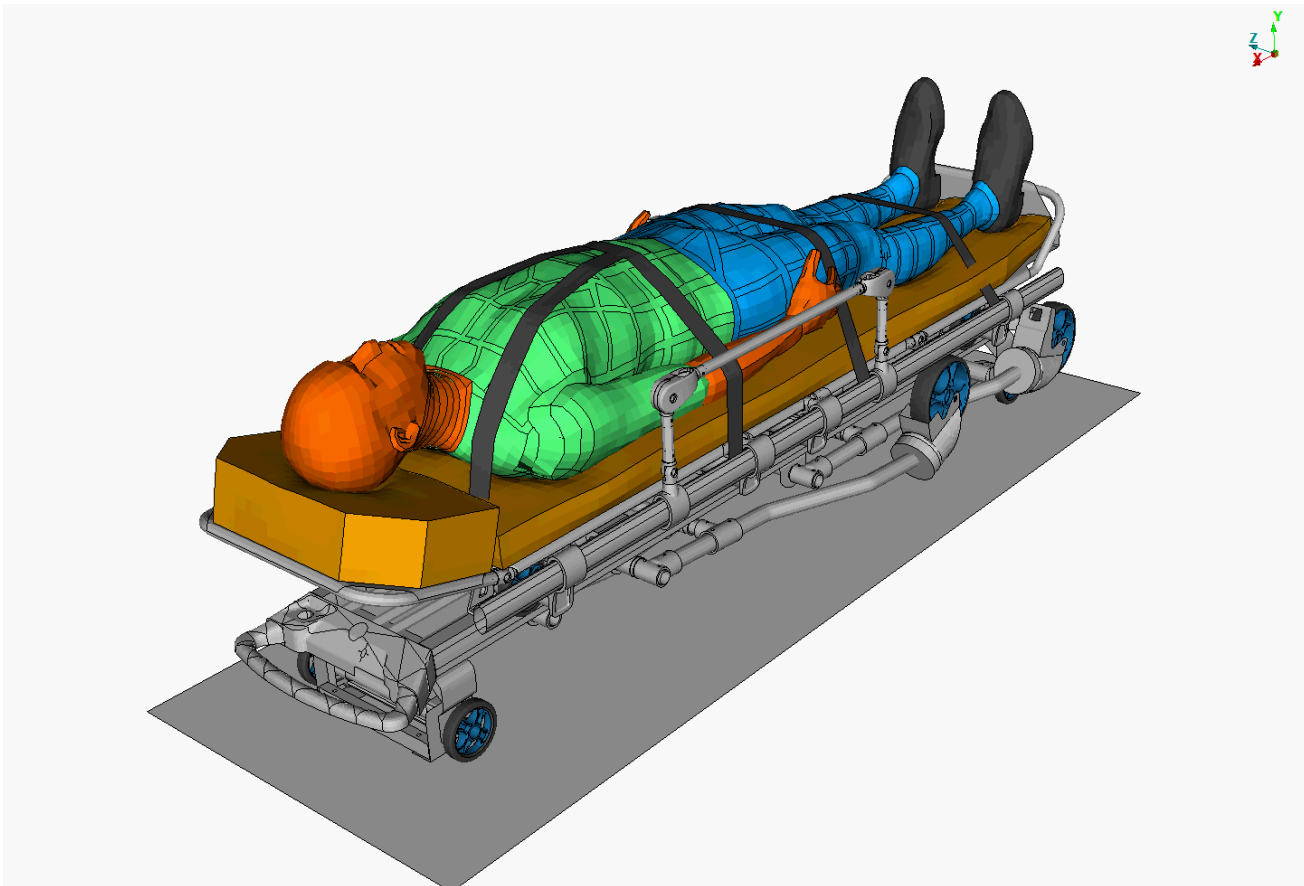


Source (all figures): Vision Consulting Automotive

Applications – Ambulance impact

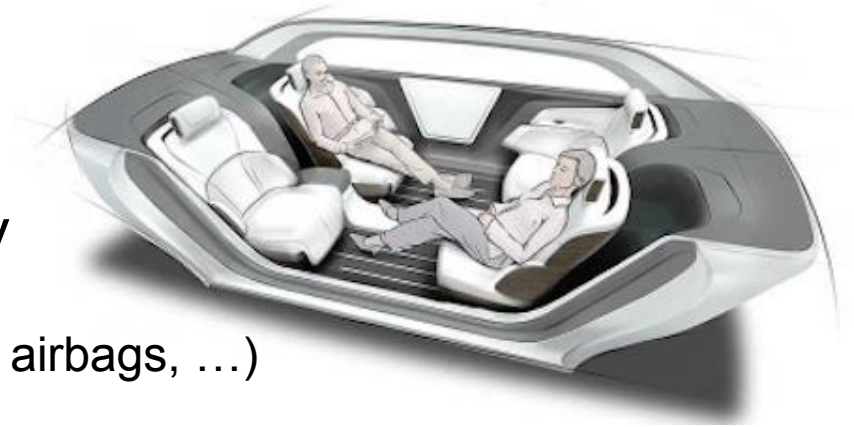
- Results

- *Impact simulation in 5 directions*
- *Trolley with stretcher meets the requirements of DIN EN 1789*



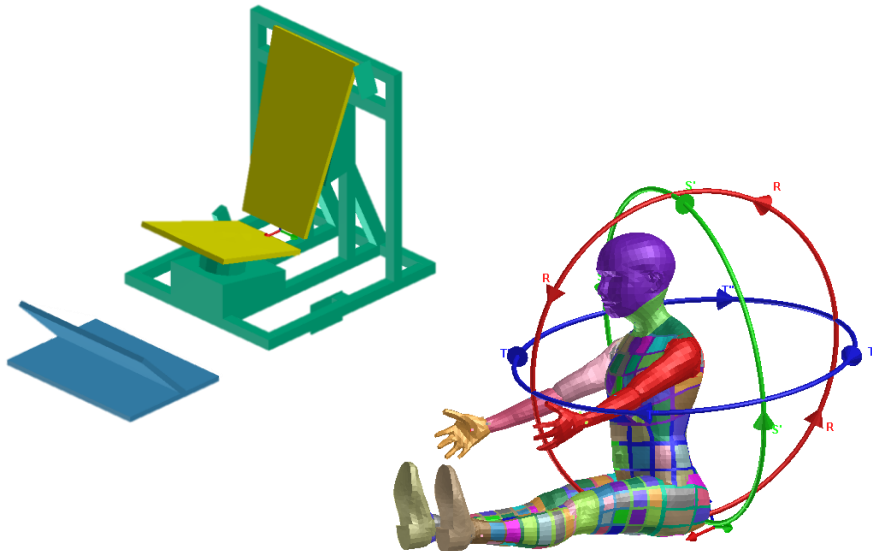
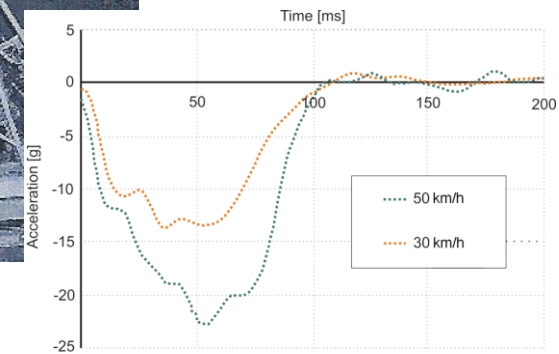
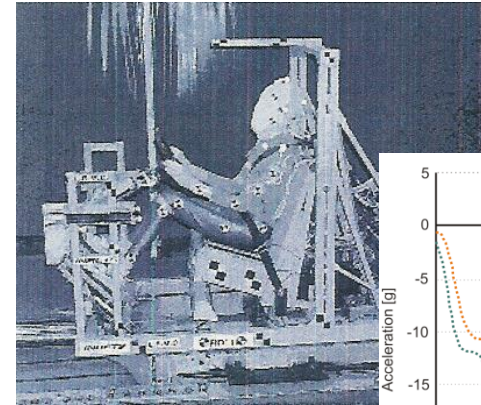
Non-standard seating

- Future mobility
 - Non-standard seating options
 - Various impact directions
- Challenges of occupant safety
 - Seat design
 - Safety elements (restraint systems, airbags, ...)
- Goal
 - Preliminary parametric study
 - Different impact velocities
 - Various impact directions
 - Different safety belts
 - Various anthropometric types



Non-standard seating

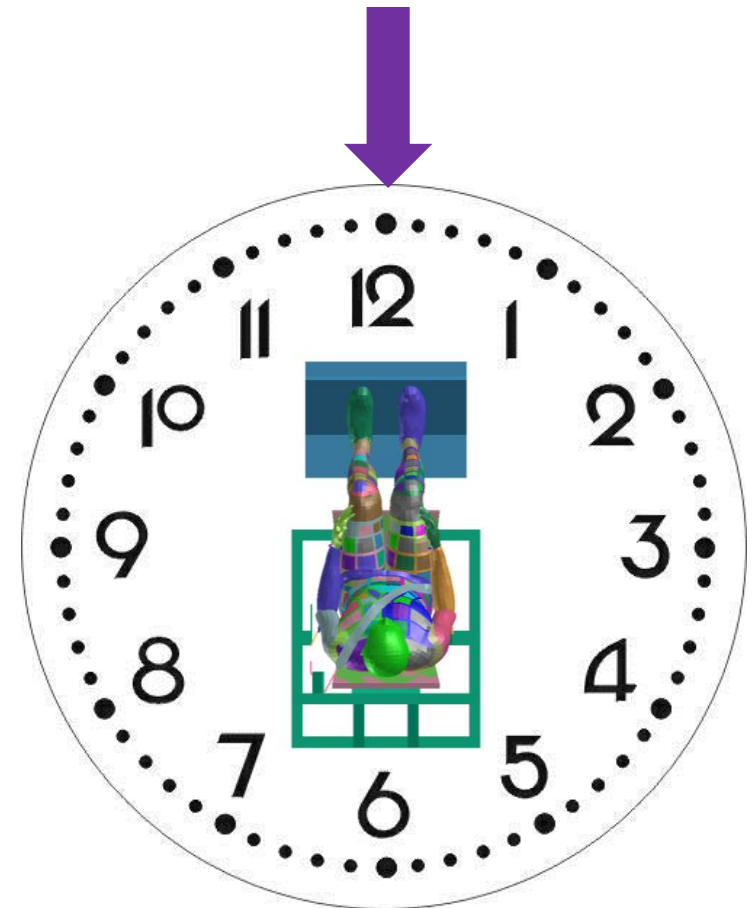
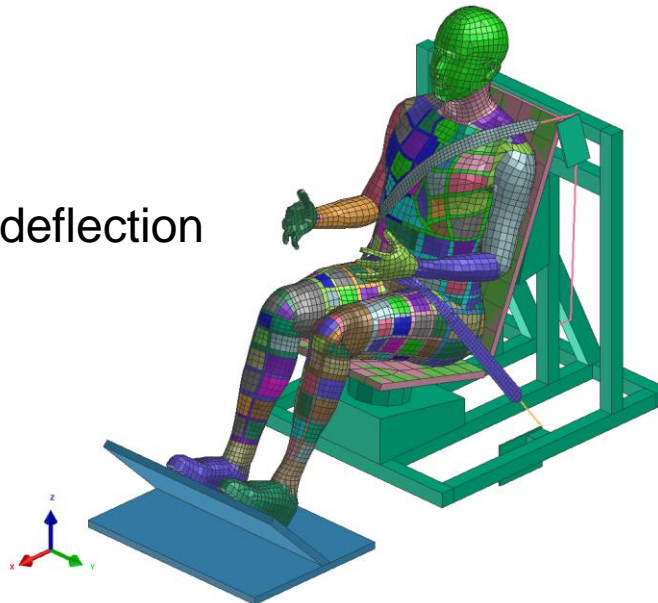
- **Baseline**
 - Sled test according to Vezin
 - Frontal impact (30 and 50 km/h)
- **Models**
 - Sled model (rigid)
 - Belt models (3p, 4p)
 - Scaled Virthuman models



Age [years]	Percentile P [%]	Height [cm]	Mass [kg]
6-7	5	112	18
6-7	50	120	23
6-7	95	130	30
12-13	5	142	41
12-13	50	153	57
12-13	95	160	64
45-55	5	164	64
45-55	50	172	78
45-55	95	184	95

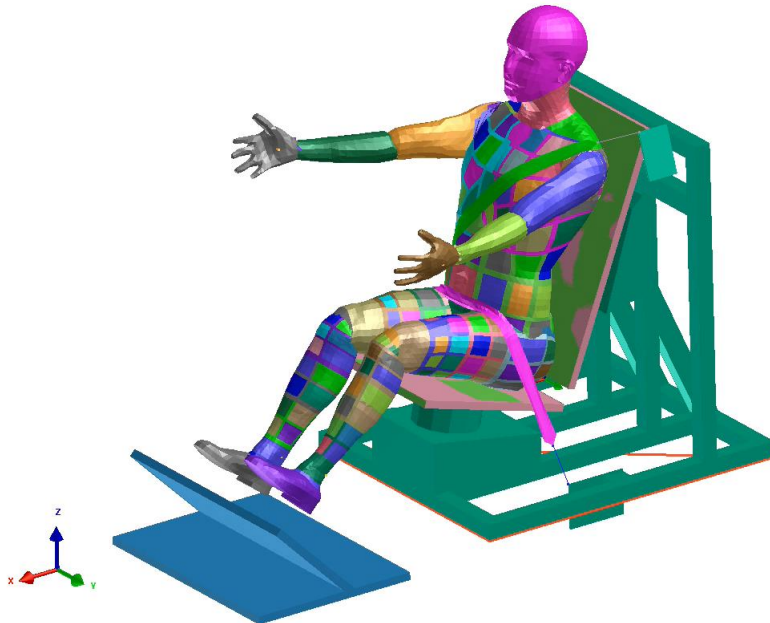
Non-standard seating

- Setting
 - Two impact velocities (30 and 50 km/h)
 - 12 impact directions
 - Two safety belts (3p, 4p)
 - 9 anthropometric types
 - 432 simulations in total
 - **Soufiane El Fani**
- Output
 - HIC
 - N_{ij}
 - Thoracic deflection



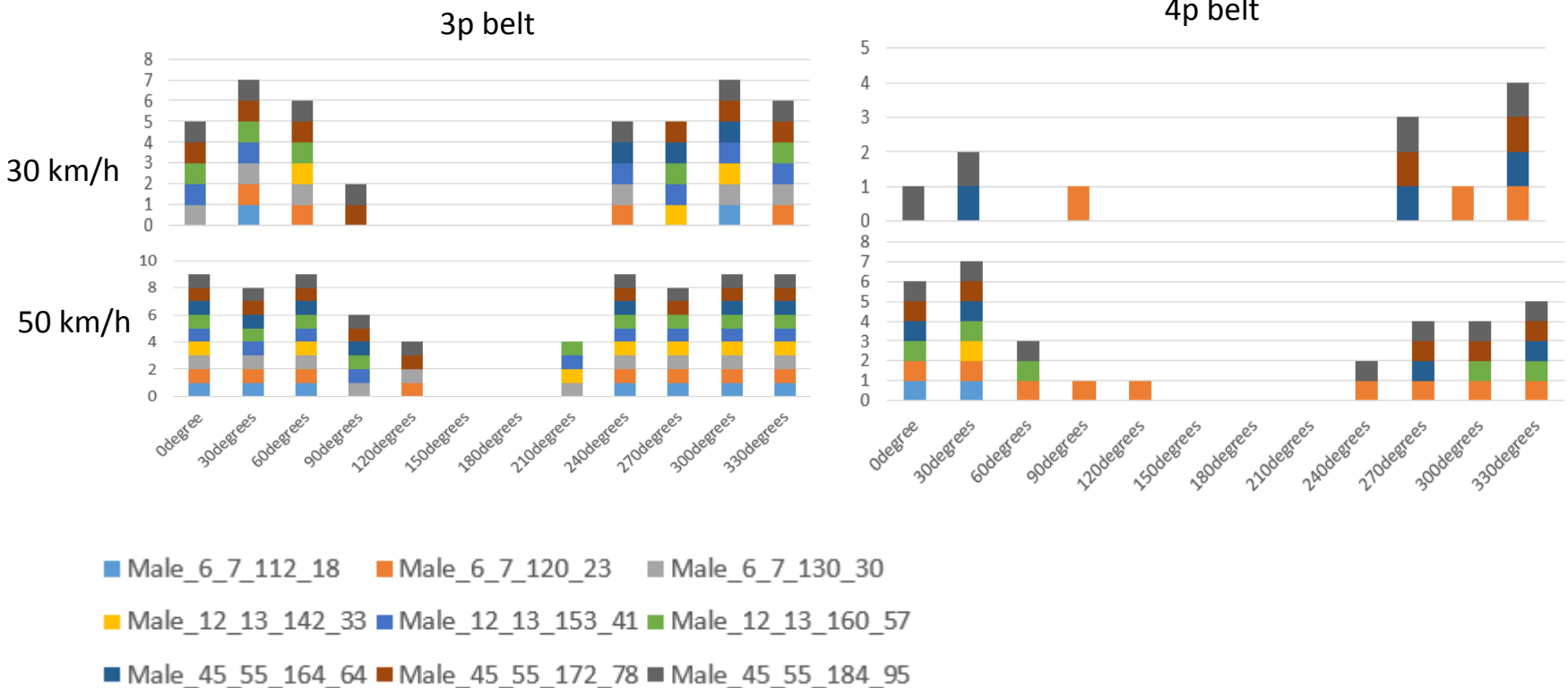
Non-standard seating

- Results example
 - Male 12-13YO, 160cm, 57 kg
 - 30 km/h, -30 deg (11 o'clock)



Non-standard seating

- Results example
 - Thoracic deflection
 - Safe option: 4p belt, rearward seating

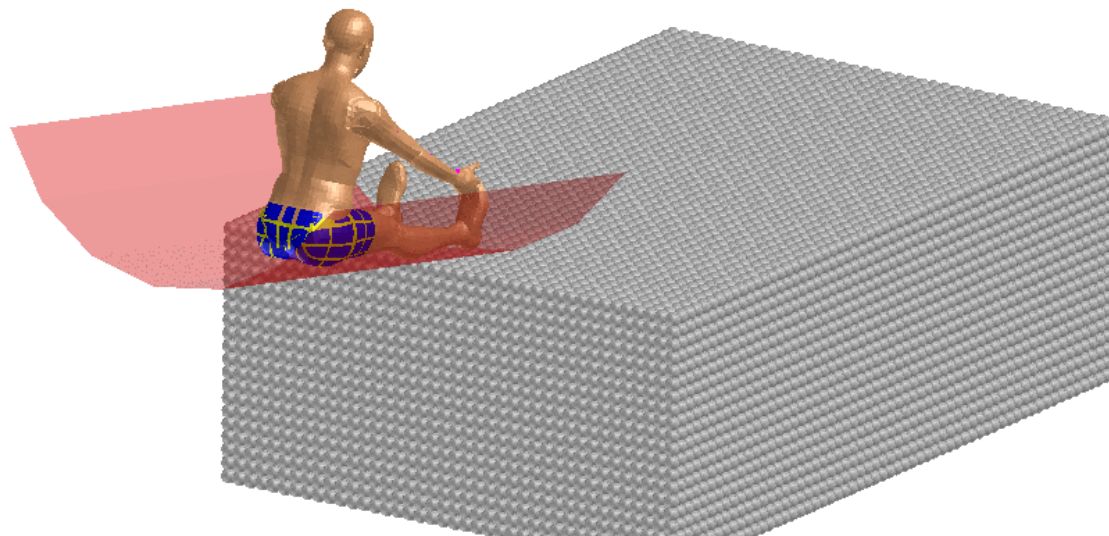


- Virtual human model for safety assessment
 - MBS model with deformable segments
 - Automatic evaluation of injury criteria (780 curves)
 - Tool for fast calculations (432 simulations with common PC)
- Challenges of future safety
 - Non-standard seating configurations
 - Multi-directional impacts
 - Aging population
 - Virtual prototyping
- Virtual approaches to be addressed



Thank You for attention!

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