Wissensforum

Human Body Modelling in Automotive Safety
Berlin, November 28-29, 2017

PIPER Open Source framework for Human Body Models: status and perspectives

Philippe Beillas

Lyon 1 IFSTTAR

piper-project.org

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PIPER

PIPER Motivation: limited HBM use

- 2012: HBM use limited <u>despite</u> performance (vs. dummies). 2017…
- We have HBM<u>s</u> ➔ Challenges???
  - 1 seated & 1 standing posture vs. positioning in vehicle<u>s</u>
  - ~~human variability (=strength)~~ mostly dummy dimensions
  - Specification? Certification? Procedures?
  - Openness? Reproducibility? Compare to dummies…
  - Business model?

➔ technical and organizational

PIPER objectives

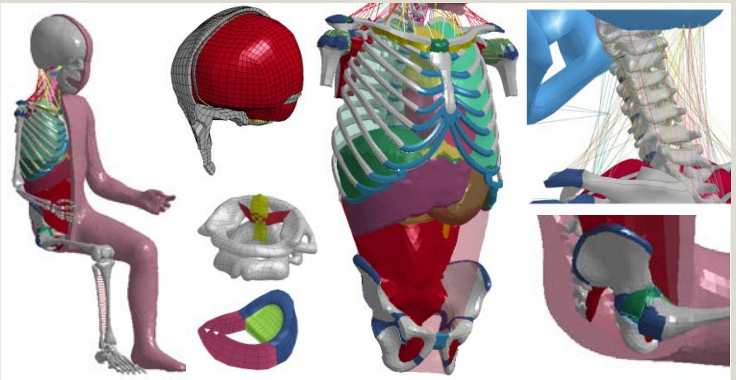
- Work on both technical and organizational issues
- 2013-2017: PIPER EU project (FP7)
  - Open Source PIPER (1) Software framework for Scaling & Positioning (2) PIPER Child model.
  - Publication process still ongoing
- 2017-… PIPER Open Source project: www.piper-project.org
  - Aim: promote HBM use for transportation safety; Open Source / Open Science, open to diversity of practices…
  - Help coordinate, manage, support, animate efforts around PIPER…

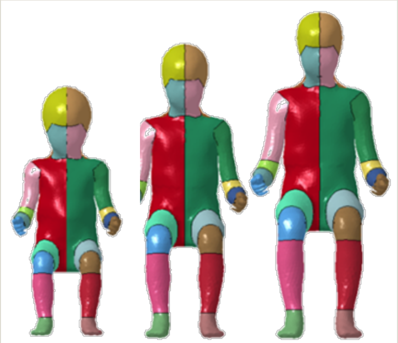
PIPER Scalable child model

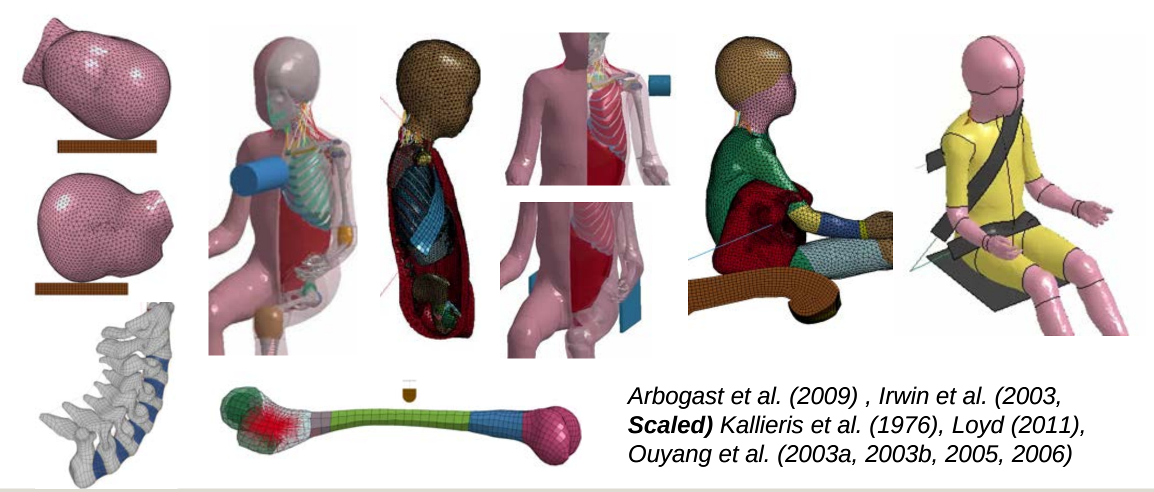
- Motivation: large changes with age, HBM less advanced than adult, variety of restrains…

➔ **PIPER Scalable model**

- Mostly deformable, ~550k elt, 0.32µs, LS Dyna
- 6YO base, continuously scalable
- 20+ validation setups (mostly PMHS), Frontal & side
- Interpolates quite well known responses (1.5-6 YO)

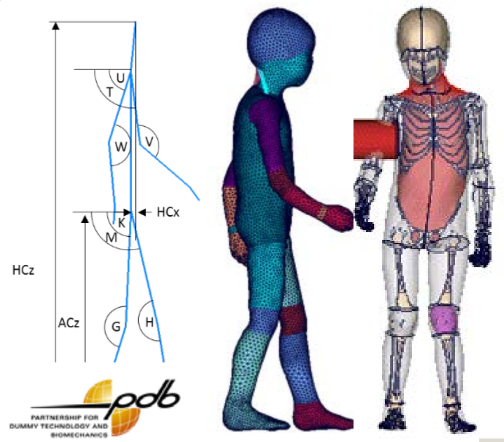






PIPER Scalable child model

- GPLv3 +Open Science +liability (see license) = Can use freely (incl. commercial)
  - IF [modify AND (distribute OR publish)] THEN modifications under same license.
- Limitations and perspectives:
  - *Validation*: few more setups +age, hip issue, CORA
  - *Scaling:* improve (cartilage, skeletal, material), extend (10+)
  - *Injury:* need accident reconstructions
  - *Pedestrian:* ongoing, PDB outside PIPER: posture, valid…

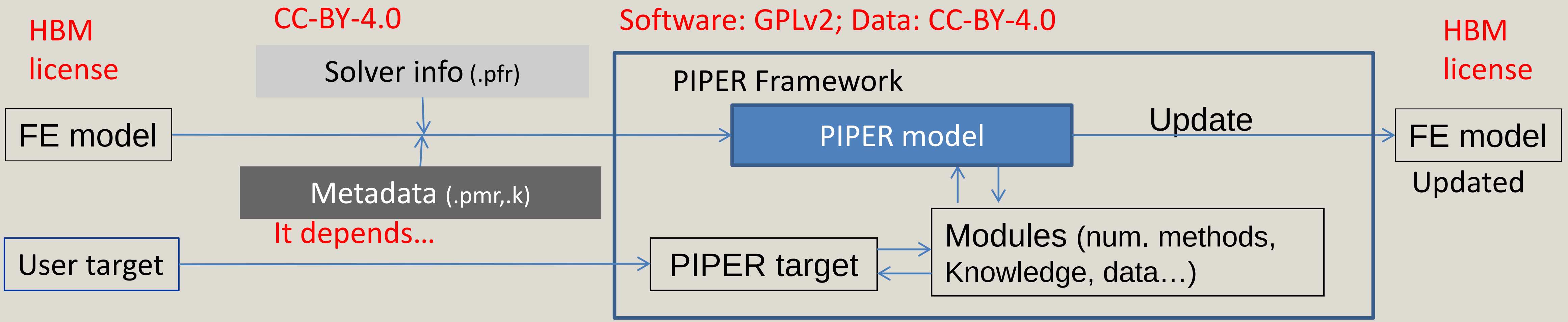


PIPER Software Framework: concept?

- Scaling & Positioning (S&P) HBM is a basic need (NOT new)
  - Practice is diverse: custom scripts, simulation…
  - HBM are "similar" (bones, contacts…); knowledge **relevant** for S&P (e.g. anthro) often not in HBM (focus=20g)
- PIPER: share S&P knowledge and num. methods between HBMs
  - HBM/solver agnostic: use HBMs as-is including IP (no change required, respect modelling intention)…

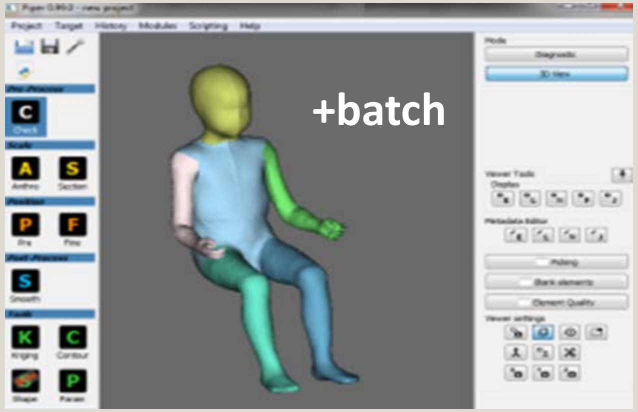
GPLv2: Free use, IF [modify AND distribute] THEN GPLv2 for modif.
CC-BY-4.0: Free use (including commercial), mix. Only need to cite

Modular framework



User editable rules: import **only what is needed/relevant for framework/modules**

- Solver = HBM independent (e.g. nodes)
- Metadata = associate entity to concept relevant for module (anatomyDB)



- Can add modules
- C++, Qt, VTK, Sofa, Eigen; **Python**, **Octave**; Win / Lin

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Metadata / Status and HBM support

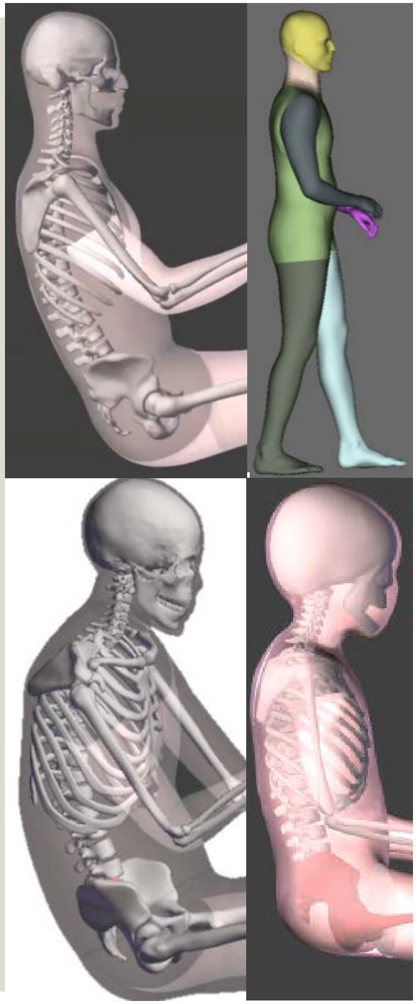
= like an “input deck” for modules → affects performance +module support

- Tried to make process “simple” and application independent… Not easy…

- PIPER developed metadata (with module support):
  - **GHBMC M50-O v4.1**: all modules (+v4.4, pedestrian). License: CC-BY-4.0
  - **THUMS AM50 v4.0.2**: most modules (no contour). Distributed by JSOL
  - **PIPER child**: most modules (contours: experimental). License: Open as model
  - **ViVA**: very basic (needs work). License: Open as model

- Third party efforts (not affiliated):
  - Elemance: **GHBMC** M50-O v4.5, pedestrian M50-PS v1.2. License: see Elemance website
  - Univ. of Munich: **THUMS** (Ongoing)
  - Univ. of Stuttgart: **ViVA** (Ongoing)…

Elemance LMU Ludwig-Maximilians-Universität München University of Stuttgart Germany Institute of Engineering and Computational Mechanics



Scaling modules and workflows

- Objective: transform HBM to match individual or population (keeping a reasonable element quality) :
  1. target definition. User intention (poll: global descriptors) +data, statistics…
  2. Association with HBM(s) (source ➔ target)
  3. Morphing: interpolation function (num. method)

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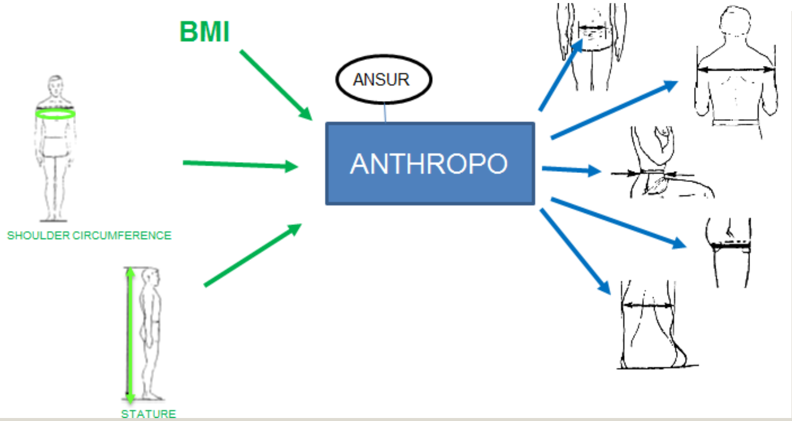
Scaling modules

A Anthro

Predict likely anthro.

- Dynamic regressions (Parkinson Reed, 2010)
- 3 public DB included (ANSUR, Snyder, CEESAR)

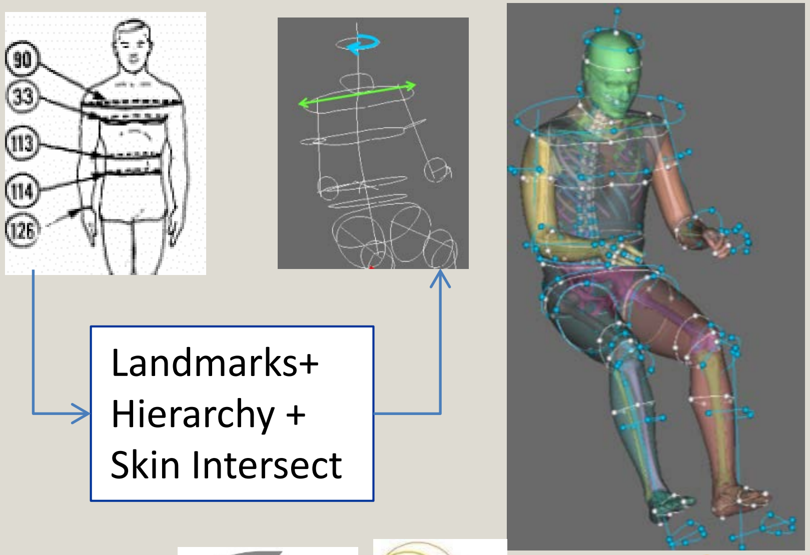
  +Gebod regressions



S Scal. Const.

Associate anthro to HBM

- Hierarchical, fully interactive
- HBM “independent” (landmark based)
- Defines *control points*
- Examples provided (CC-BY-4.0)



Southampton ceesar Lyon Inria FITT

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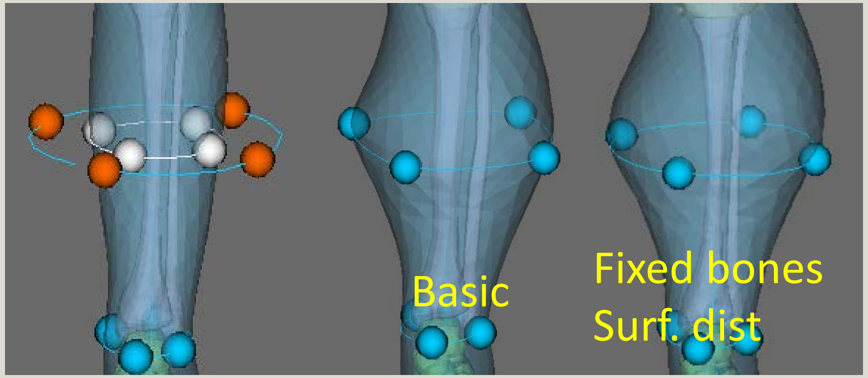
Scaling modules

Kriging

Interpolation based on control points (CP)

- Many options: intermediate target (skeleton/skin), smooth or not, Any number of CP (box subdivision), geodesic distance…



And a few others…

Param

Parameter

- Help scaling material…

Contour

Contour scaling

- Use skin contours as handles for interpolation (bones vs soft around)

Child

PIPER Child scaling (dedicated)

- GEBOD +local features +kriging +material (experimental)

Shape

Shape sculpting (experimental)

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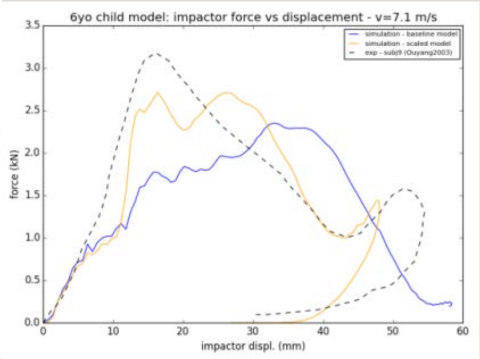
A few scaling examples

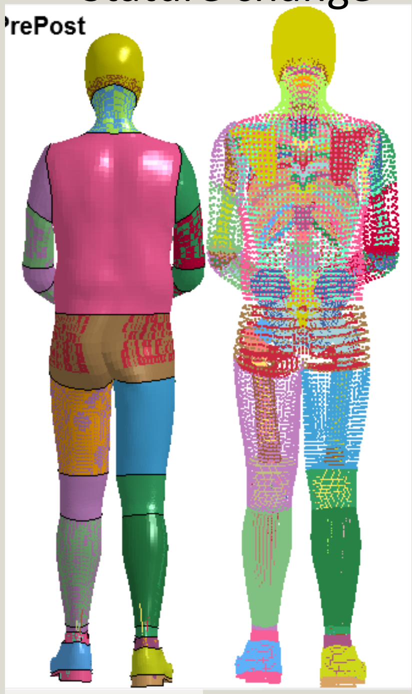
To PMHS…



To extreme range represented by Q3 in reg. R129

PoCC 2017 next week in Munich

GHBMC pedestrian
Stature change

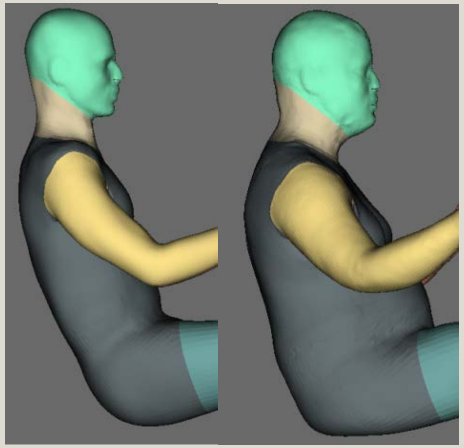


1m72
65kg

1m79
75 kg

GHBMC
thin
thigh

GHBMC
obese
(BMI35)



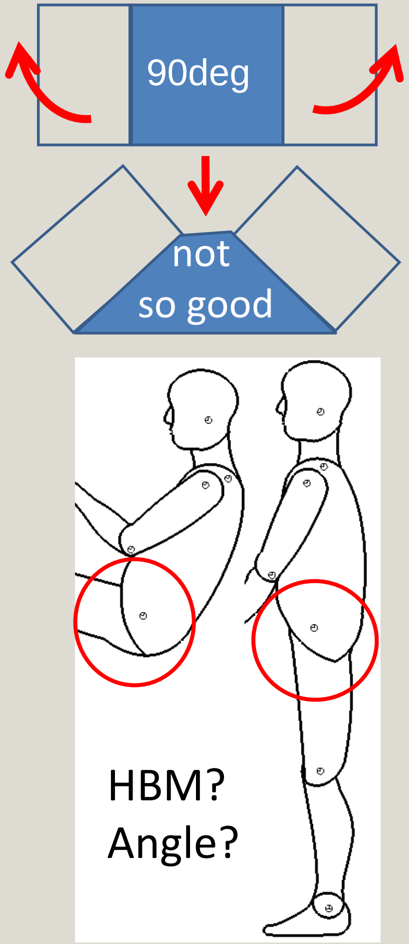
LAB CEESAR Lyon 1 KTH

Scaling modules and workflows: summary

- Several applications performed, many options, relatively fast, potentially HBM independent
  - Need more evaluation and testing: target validation, response…
- Limitations and perspectives
  - Need visual feedback on quality of regressions
  - Scaling by skin only can create skeletal artefacts ➔ integrate more internal (bone) constraints with regression… Open data??
  - …

Positioning modules and workflows

- Objective: move HBM to desired(?) posture
  - Challenges: target posture definition; Geom. method: sliding?, FE simulation: cost. Both: realism?
  - Element quality: Let's be realistic too… (assumption: no remeshing)
- PIPER Approach: separate posture definition from FE mesh transformation



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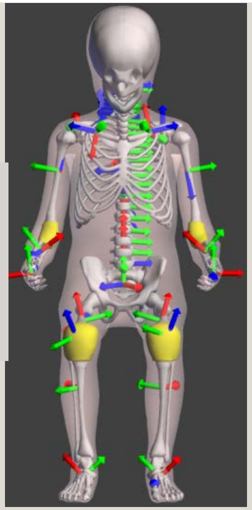
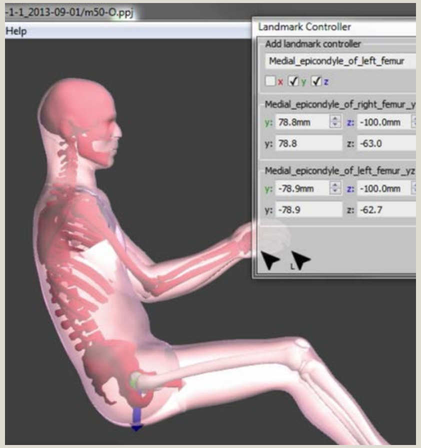
Pre-positioning module: compute plausible posture

- Lightweight physics simulation
  - Meshless; Sofa framework
- HBM compatible Model built at import (metadata)
  - Rigid bones, joints, collision, contacts, soft tissues (interp. based on voxelization)
  - e.g. ~3 min GHBMC (default parameters)
- <u>Interactive</u> simulation under constraints:
  - Fixed bones
  - User controllers: angles, positions, landmarks
  - *A priori*: for now, only spine curvature
- Target position saved once acceptable





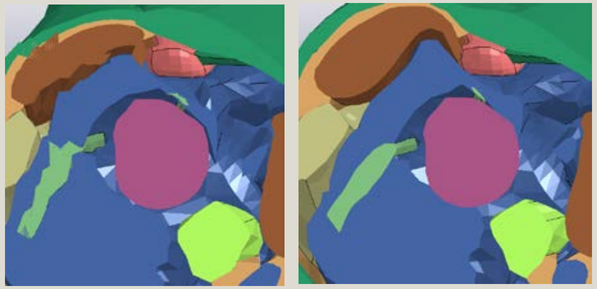
Inria Lyon 1

Positioning: four mesh transformation options

- Depending on range of motion, HBM…

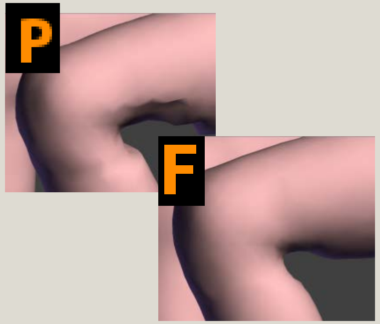
+ Smoothing after (often useful)

Smooth
- Mesh: 3D or 2D
- Transformation (bone +skin constraints)

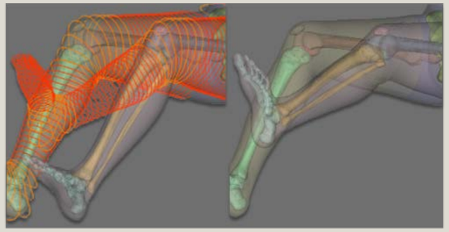


Pre — direct transform

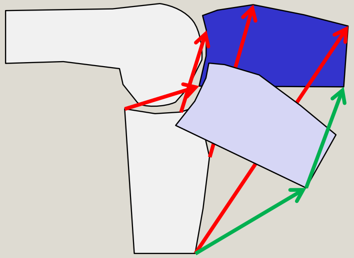
Fine — = P +refined voxels +more interp. frames ➔ better soft tissues



Contour — Contours handle soft tissues transformation



Export input deck for FE simulation (pull bones by beams, incl. interm. Positions)



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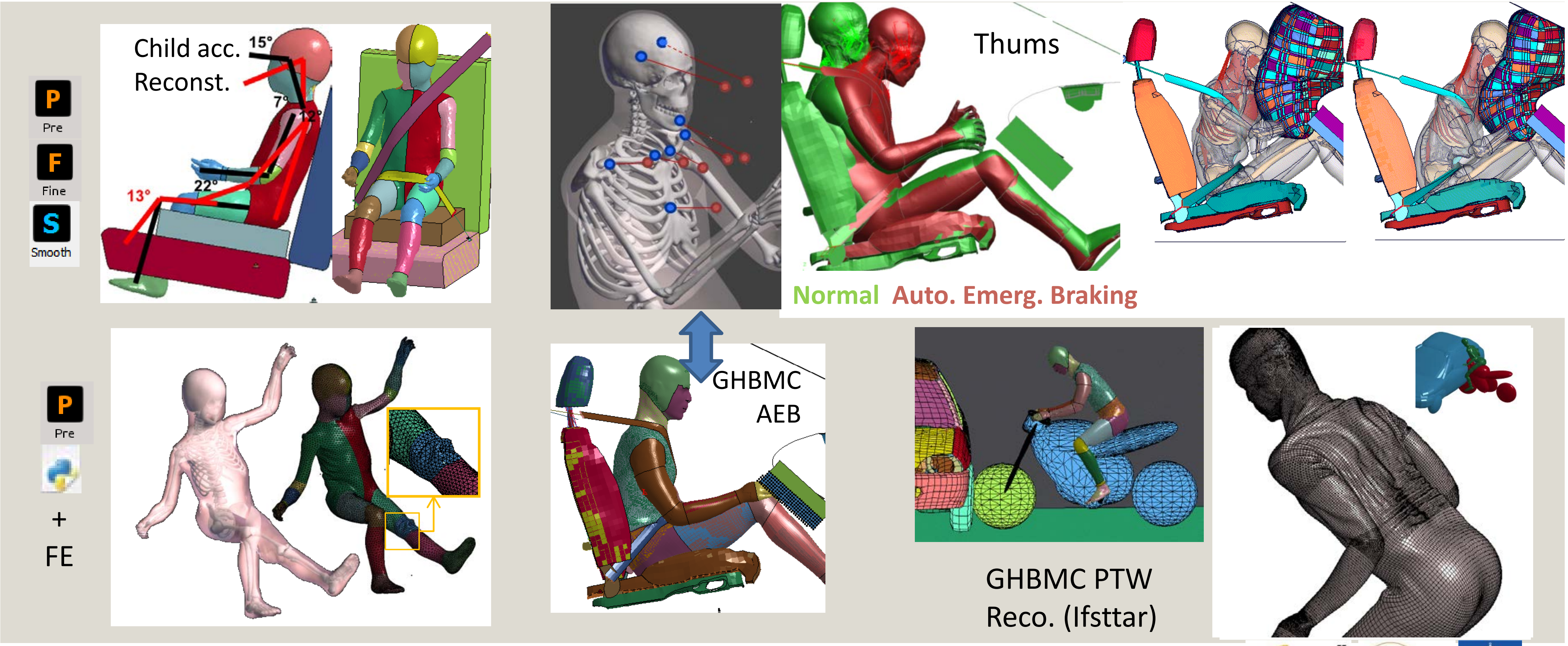
A few positioning examples



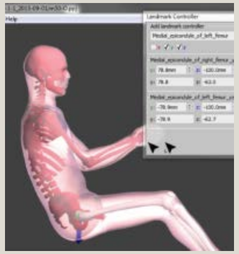
Lyon 1

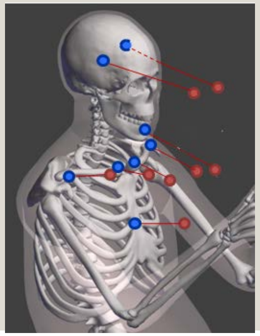
Positioning modules and workflows

- New pre-position coupled with transformation approaches. Some applications
  - Which method to use? Need more testing / practice…
  - Realism? (geom: volume conservation?; FE: folds?; initial strain); Response?
- Other limitations and perspectives
  - More constraints (e.g. postural preferences, ROM=f(age), coupling…)
  - Stability and speed could be improved a bit (multicore)
  - HBM not always designed for positioning: time for some changes?
  - …

PIPER Summary

- Software for S&P (HBM neutral, some “advanced” methods, many possible workflows), Scalable child HBM, Open Source, Free.
- <u>There are limitations (we acknowledge them)</u>
  - Testing/feedback needed. Already potential for applications (we think)
  - Contributions (any kind) are welcomed!
- Activities started at both academic and commercial places
  - A lot of interest. We hope a “community” can develop…
  - We would love to know what you are trying to do, what does (not) work, what you think ➔ don’t stay isolated
  - We hope for a user meeting next year…

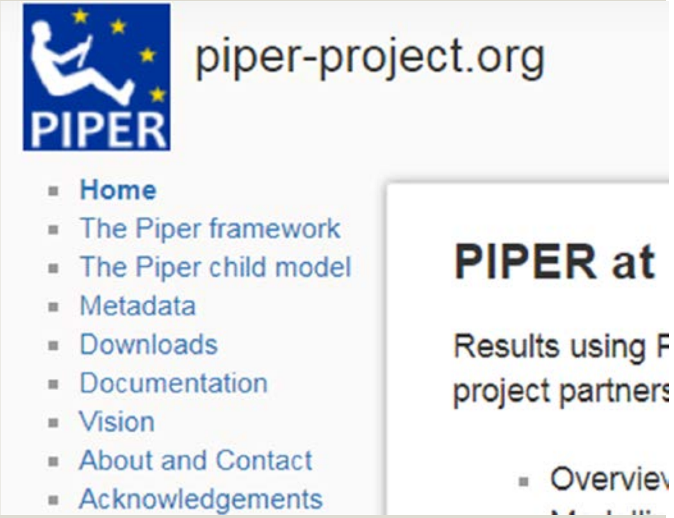




Thank you for your attention!

- Question? Comments?

- piper-project.org
  - manual, executables, datasets, models, videos, code, models, forum, wiki, tutorials, vision, FAQ…
- Contact: forum is preferred (*Called "Issues"*)
  - Direct contact: contact@piper-project.org (philippe.beillas@ifsttar.fr)



PIPER Active session: examples and interactions

- Examples of recent/ongoing work

1. Obesity and submarining: scaling the GHBMC (P. Beillas)
2. Metadata definition (T. Fuchs, LMU)
3. PIPER Child: Accident reconstructions (P. Petit, for KTH)
4. Pedestrian simulation: the effect of stature (P. Petit, LAB)

- Followed by general discussion

Example 1

Obesity and submarining

A first attempt to scale the GHBMC M50 to an obese subject using the PIPER software

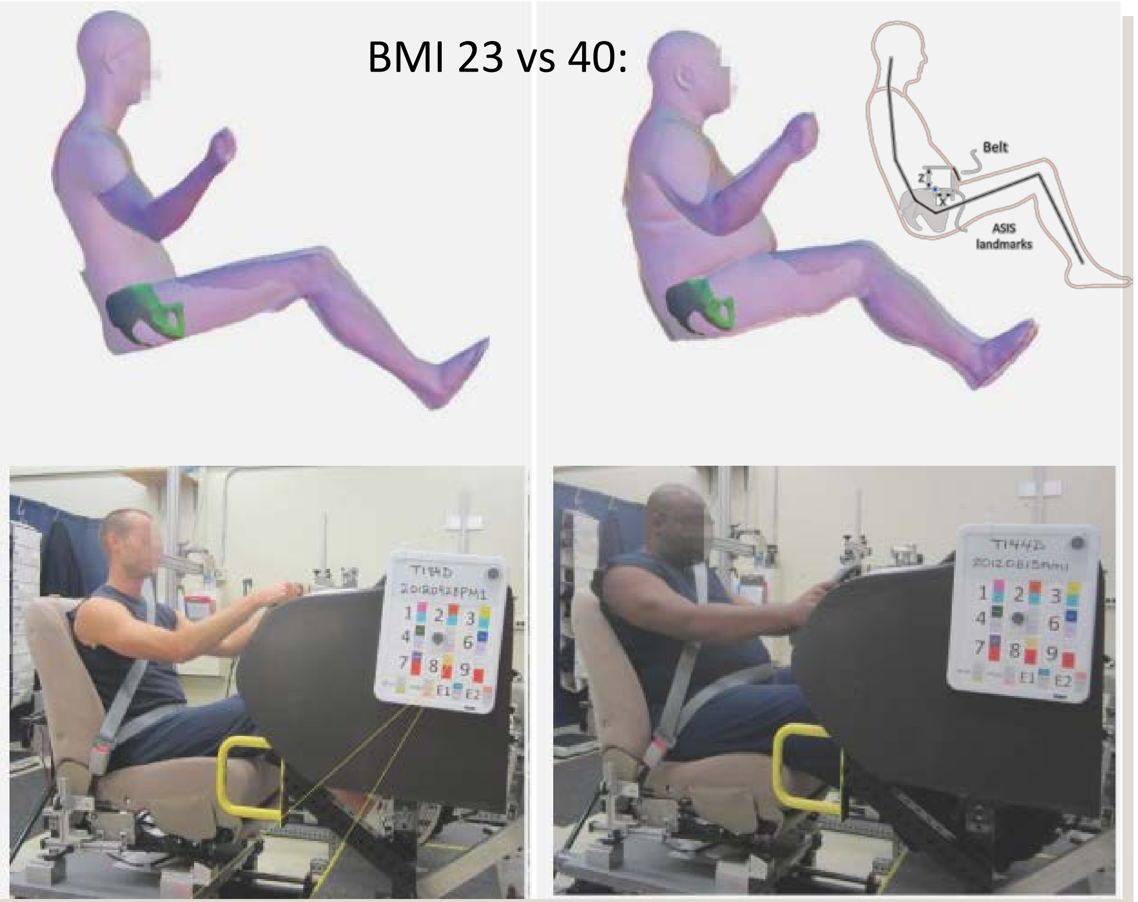
Tomas Janak,
(PhD candidate)
Yoann Lafon,
Philippe Beillas

Philippe Petit

Introduction and objectives

- Context: obesity trend, interaction with restraint systems, submarining
- Present first attempt to scale GHBMC M50 (BMI ~25) ➔ Obese (BMI 35)
  - With existing data and PIPER software

BMI=Body Mass Index (kg/m2)



Lap belt fit issue (Image courtesy of Jingwen Hu, Jonathan Rupp, Matthew P. Reed. UMTRI)

Approach and target definition

- Data: UMTRI Adultshape (*UAS)*
- *UAS* ≠ GHBMC: posture, size

➔ GHBMC scaling in 2 steps

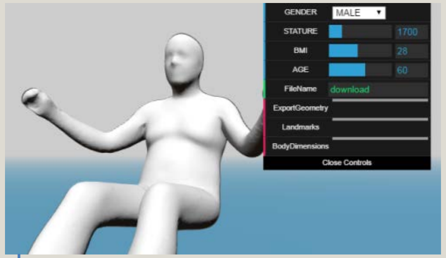
  ➔ closest *UAS@BMI25* using skin only

    - *Hyp.: the ratio skin/bone is similar*

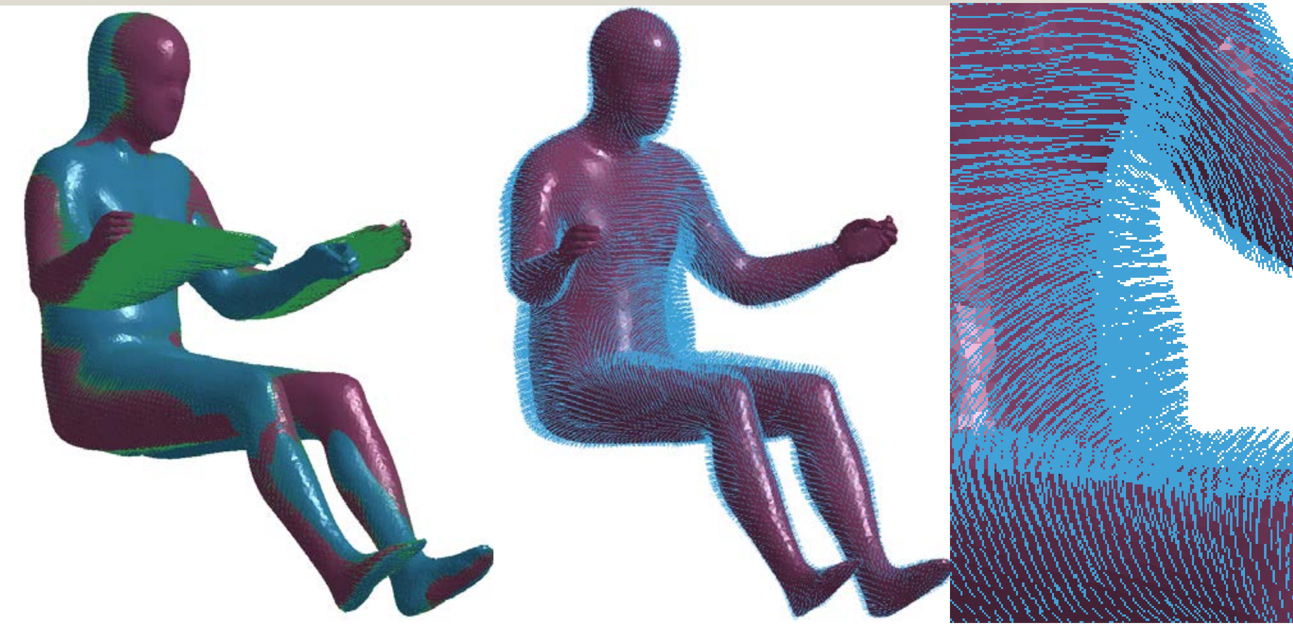
  ➔ *UAS@BMI35* with fixed skeleton

- Preparation: many steps…
  - Artefacts (hands, folds…)
  - Registration (mHBM software) to associate and define control points
  - Correction to fit BMI25 in BMI35

http://adultshape.org



GHBMC 1749mm vs. Adultshape 1850mm (28YO, BMI 25.17)



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PIPER methodology

Kriging

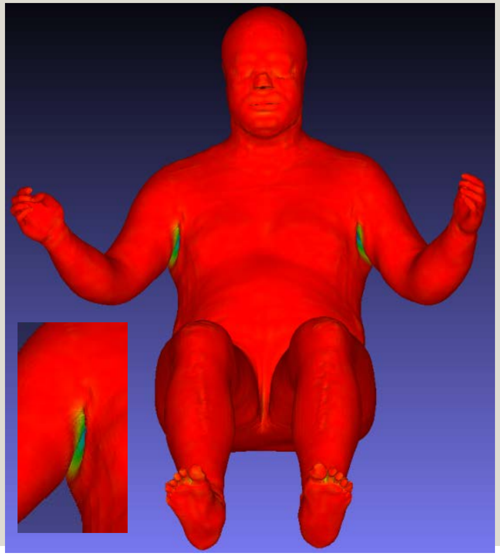
- Fixed bones +skin surface= ~280,000 control points ➔ PIPER Kriging: auto. box subdivision.
- Quality Issues Here ☹ ➔ new iterative Kriging approach:
  (1) subsample to few thousands CP, no box (2) increase number, use boxes, check accuracy

➔ Runnable model, close to target

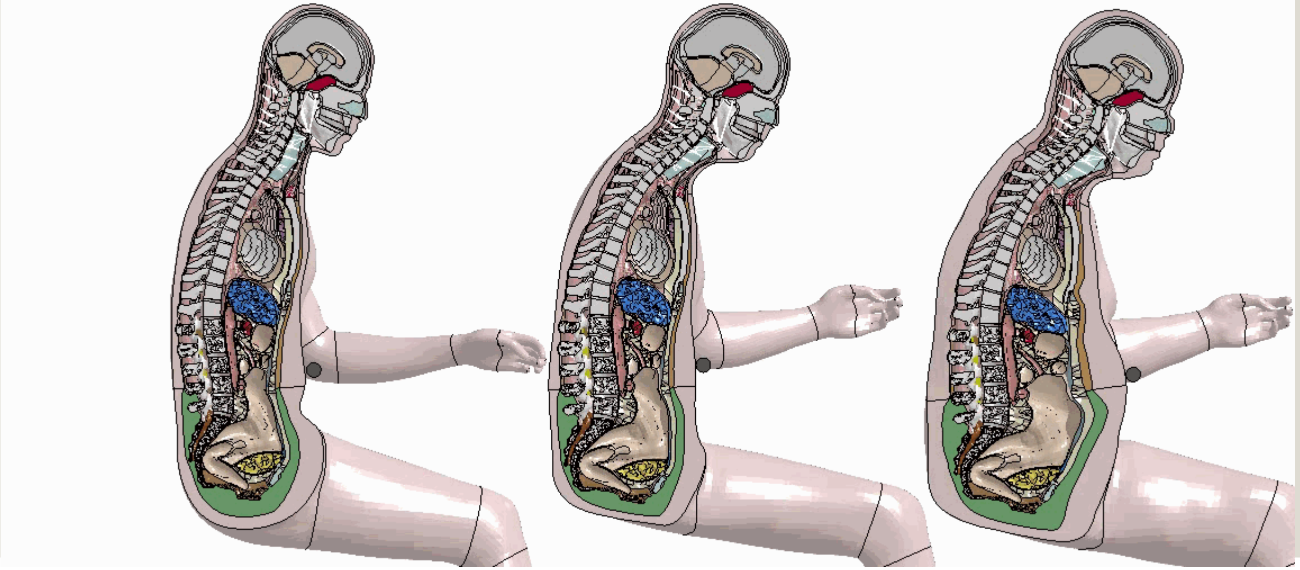
Distance to target

Mean:
0.72mm

Max (local):
69.55mm



Baseline (BMI 25) ➔ UAS (BMI 25) ➔UAS (BMI35)



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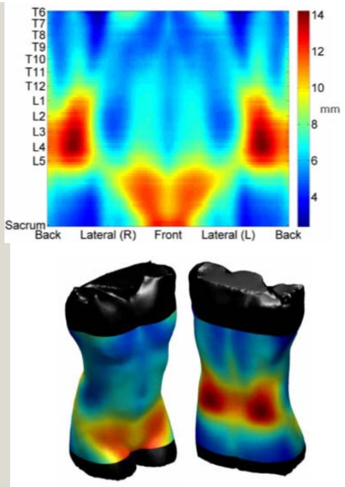
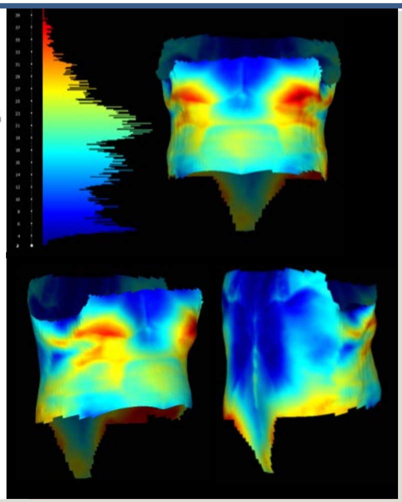
Discussion and perspectives

- BMI 25 → 35 (Obese): Realism? Subcutaneous fat thickness distribution?
- Mechanical response?
- Perspectives
  - PMHS imaging and testing
  - Constraint more the scaling (internal organs…)
  - integration of iterative kriging into PIPER release

BMI change distribution



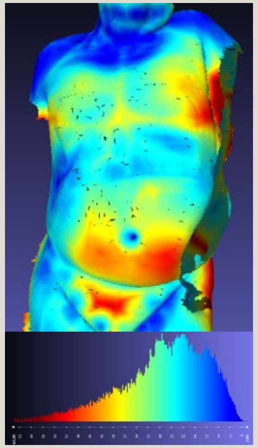
Holcombe et al.: +20Kg (linear reg., supine)

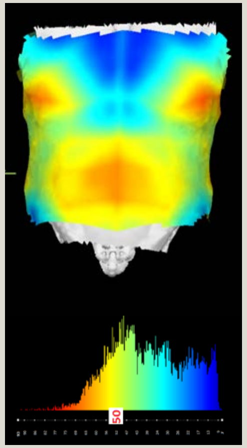


Model: +34Kg (non linear reg., seated)

BMI35 Subject comparison

CT-scan from *SICAS* *(supine)*





Model: BMI35 (seated)

Holcombe et al (Ircobi 2014), SICAS Medical Image Repository (smir.ch)

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Example 2

Defining Metadata for PIPER Positioning Tool in TUC

Therese Fuchs, Julia Muehlbauer, Anja Wagner, Steffen Peldschus

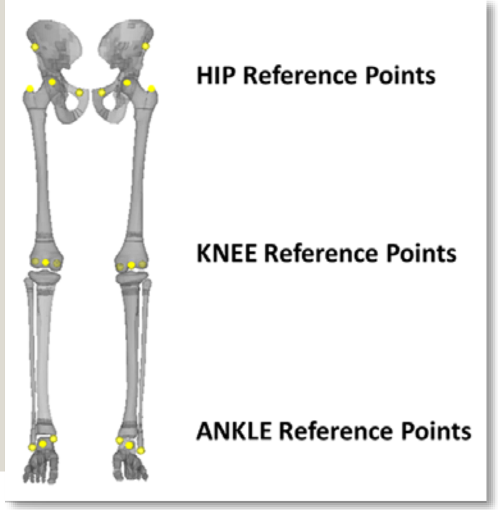
LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

THUMS User Community

Defining Metadata for PIPER Positioning Tool in TUC

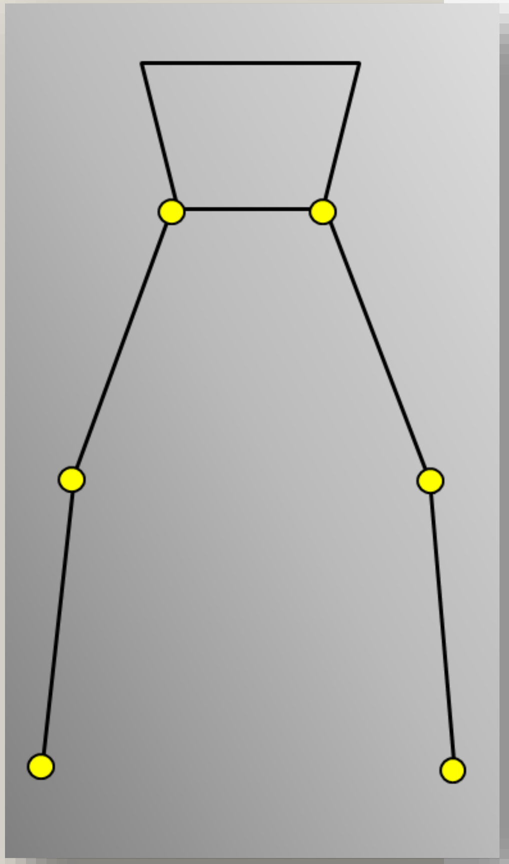
- **Motivation**
  - Applicability and accuracy of PIPER Positioning Tool highly depending on definition of metadata
  - Metadata provided only for a limited number of FE HBMs (**GHBMC M50-O v4.1, THUMS AM50 v4.0.2, PIPER child, ViVA)**
  - Different institutions working on different ways of metadata definition (i.a. Elemance, University of Stuttgart, LMU)
- **Challenges**
  - Definition of an… …data obligatory to obtain anatomi…
  - Definition of me…data subject to model changes/updates & user

TUC Reference Points for Metadata definition



Defining Metadata for PIPER Positioning Tool in TUC

- **TUC Reference Points**
  - Joint Rotation Centers/Axes: Building a kinematic chain for pedestrian/occupant positioning
  - Bony Landmarks: Points describing e.g. Pelvic Plane, Frankfurt Plane
  - Defining angles and distances to non-ambiguously describe the position of the pedestrian/occupant in the global CS
- **Challenges**
  - Definition of anatomically meaningful metadata obligatory to obtain anatomically meaningful postures
  - Definition of metadata subject to model changes/updates & user



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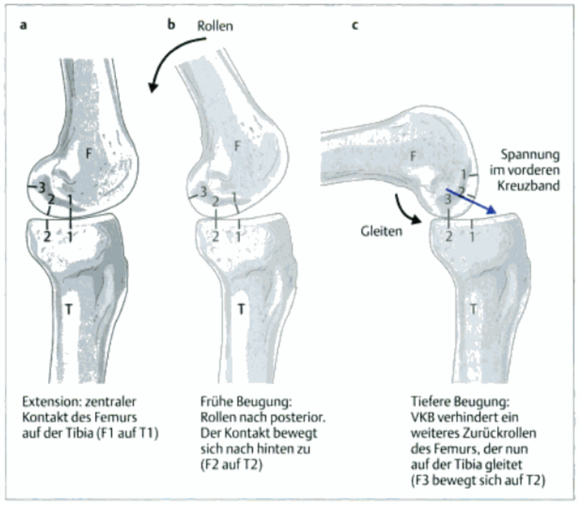
TUC THUMS User Community | LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN | PIPER

Defining Metadata for PIPER Positioning Tool in TUC

- **TUC Reference Points**
  - Definition of Points based on biomechanical testing/data published in literature
  - Definition of a clear instructions/distinct methodology for each Reference Point
  - Methodology anatomy based/independent of mesh: can be applied to any HBM
- **Challenges**
  - Definition of anatomically meaningful metadata obligatory to obtain anatomically meaningful postures
  - Definition of metadata subject to model changes/updates & user



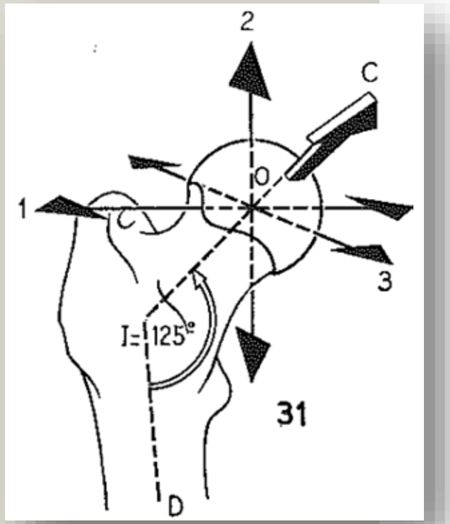
Adam (2005)

Adam 2005 Orthopädie und Orthopädische Chirurgie: Knie

Defining Metadata for PIPER Positioning Tool in TUC

- **Example**
  - **Hip Reference Point**
  - Hip = synovial ball-and-socket joint with the joint center located in the center of femoral head/acetabulum representing 2/3 of a boule with a diameter of 40-50mm
  - Instruction for defining Hip Reference Points:

    Define the Center of the acetabulum on the left and right hip bone by (1) selecting all nodes belonging to the hemi-sphere´s surface of the acetabulum and (2) calculating the point equidistant from the selected nodes.



Kapandji (1985)

Kapandji 1985 Funktionelle Anatomie der Gelenke
Burghardt 2007 Die Beingeometrie in der Frontalebene

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Defining Metadata for PIPER Positioning Tool in TUC

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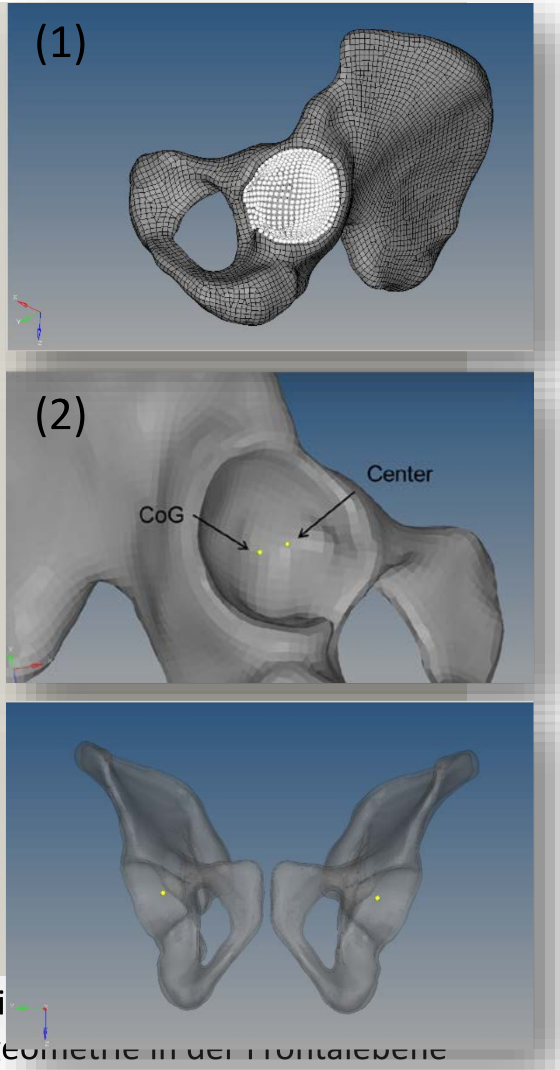
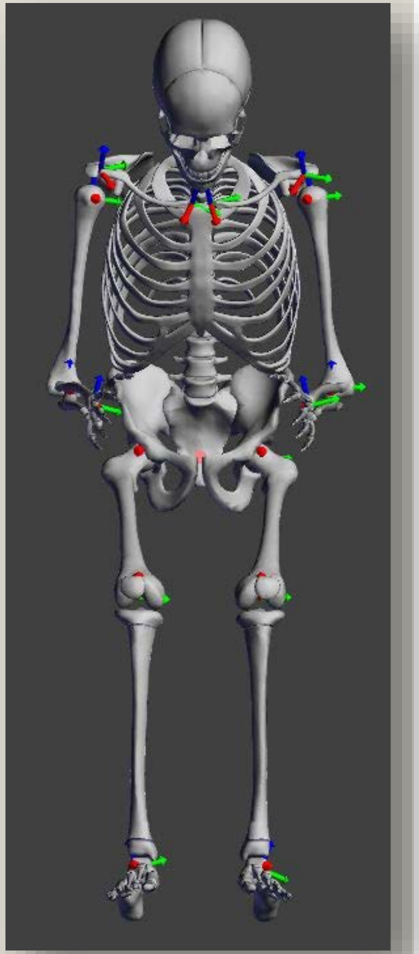
    Define the Center of the acetabulum on the left and right hip bone by (1) selecting all nodes belonging to the hemi-sphere´s surface of the acetabulum and (2) calculating the point equidistant from the selected nodes.



Kapandji 1985 Funkti
Burghardt 2007 Die Beingeometrie in der Frontalebene

Defining Metadata for PIPER Positioning Tool in TUC

- **Status – completed:**
  - Definition of Reference Points for **lower extremities, upper extremities** and **thorax** in **THUMS TUC ped. & occ.** (Abaqus, LS-DYNA, VPS)**, GHBMC M50-O v4.5** (LS-DYNA)**, THUMS V4 occ. & ped.** (LS-DYNA)
  - Definition of PIPER metadata for **THUMS TUC ped. & occ. (LS-Dyna)**
- **Status - ongoing:**
  - Definition of TUC Reference Points for **spine** and **head**
  - Instructions for TUC Reference Points definition to be made publicly available via TUC homepage



Defining Metadata for PIPER Positioning Tool in TUC

THANK YOU!

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

TUC THUMS User Community

Wissensforum

Example 3

Application: accident reconstruction with PIPER Child model and application

Ph. PETIT on behalf of

Xiaogai LI, Chiara GIORDANO and Svein KLEIVEN
(Kungliga Tekniska Hoegskolan – KTH)

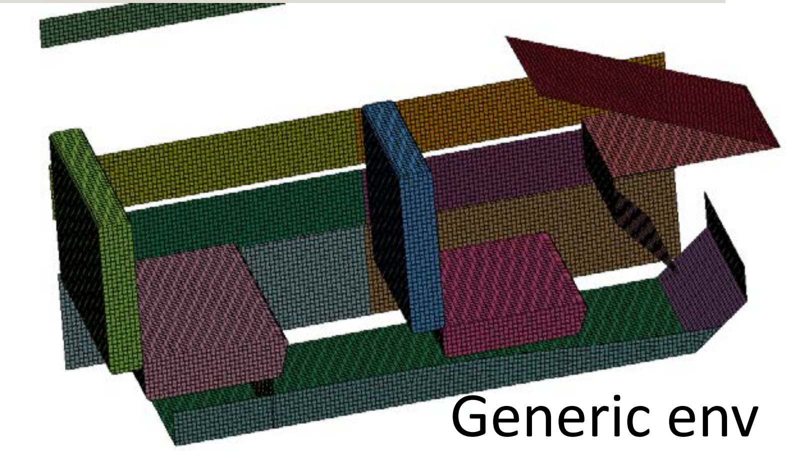
piper-project.org

PIPER

Child tolerance to impact

- Casper DB: 100+ physical reconstructions
  - performance assessment +risk curve
  - Limitations: dummy dependent, assumptions…
- Interest for HBM: same (assess, risk curve)
  - Pulse = no need for vehicle model;
  - Environment loading by dummy
  - Challenges: methodology ? Sensitivity? Etc…
- PIPER building blocks: child, software, generic environments

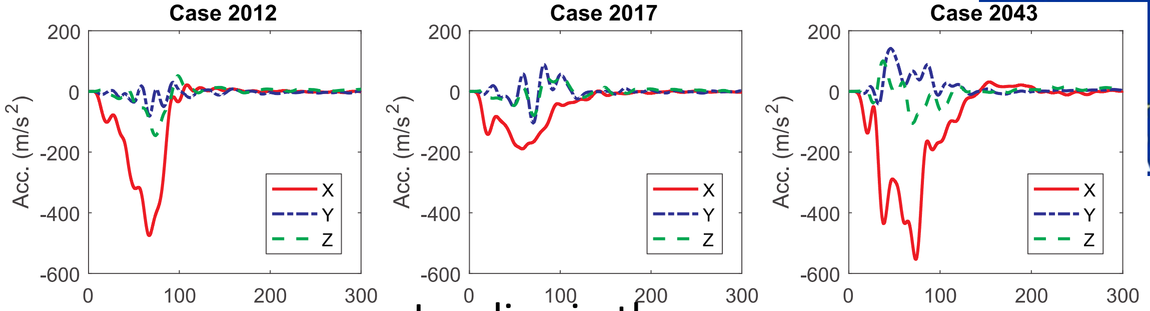
  + VFSB generic CRS (Casper) released…
- First reconstruction trials (KTH) presented today
  - Giordano et al. (2017) Plos One


Generic env


group 0 group 1 group 2

VDI Wissensforum

Rec. KTH: 3 Cases



Loading in the rec.

Case 2012

- 26 m.o
- Positioned
- Environment scaled
- CRS group 1

MAIS 4 (head)

Case 2017

- 5 y.o.
- Positioned
- Environment scaled
- CRS group 2 lower booster

MAIS 0

Case 2043

- 5 y.o
- Positioned
- Environment scaled
- CRS group 2 scaled

MAIS 6 (head & neck)

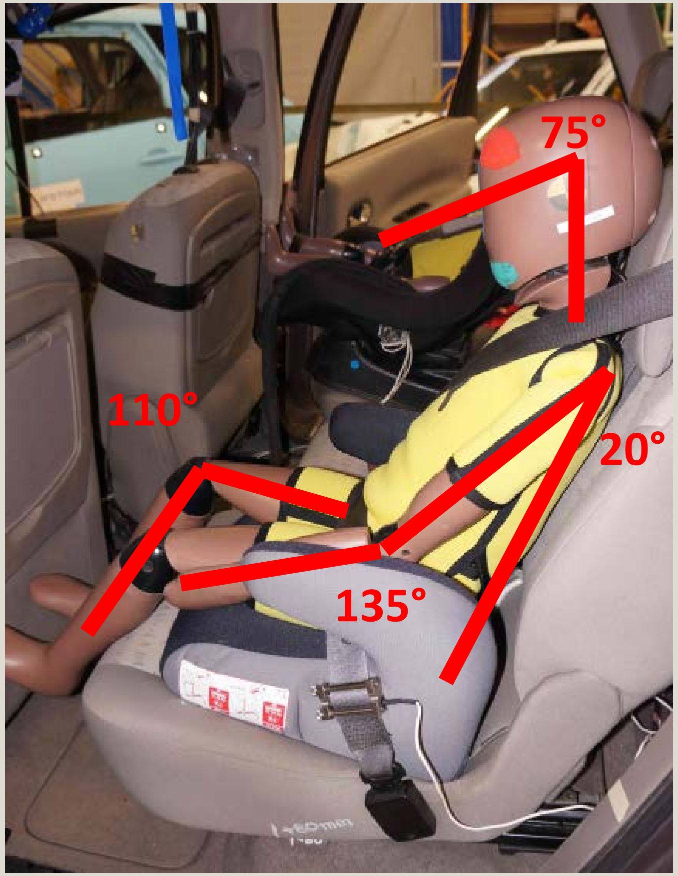
Giordano C, Li X, Kleiven S (2017). Performances of the PIPER scalable child human body model in accident reconstruction. PLoS ONE12(11): e0187916.

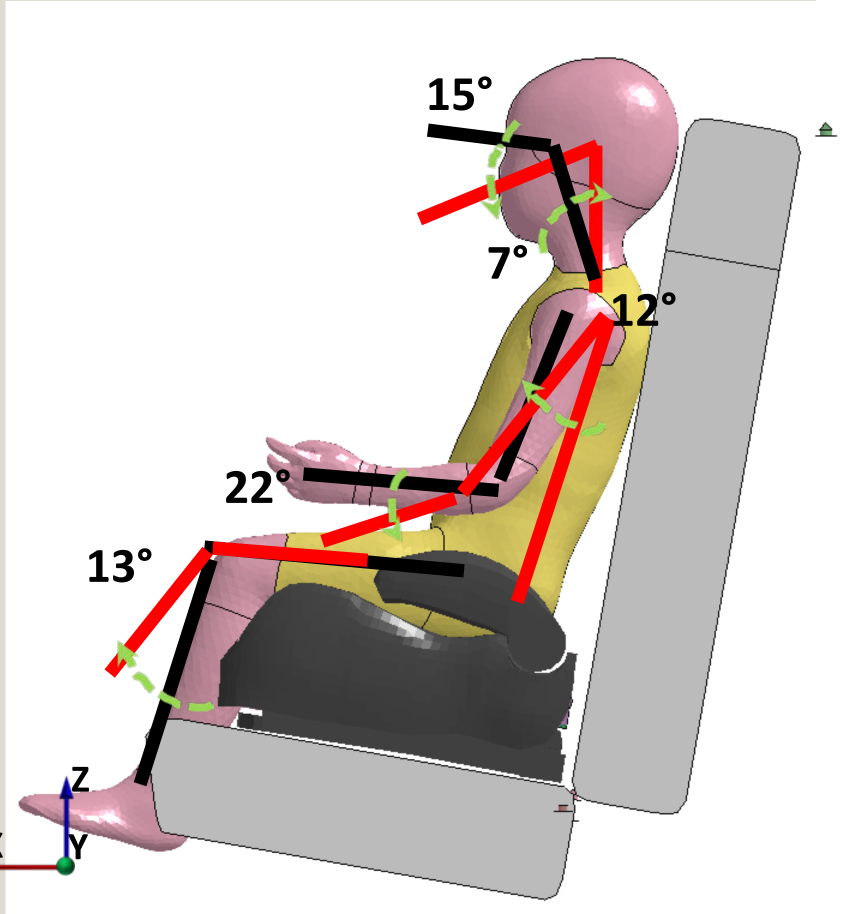
Positioning example: Case 2017

PIPER tool positioning

(Neck, head, glenohumeral, elbow, knee)

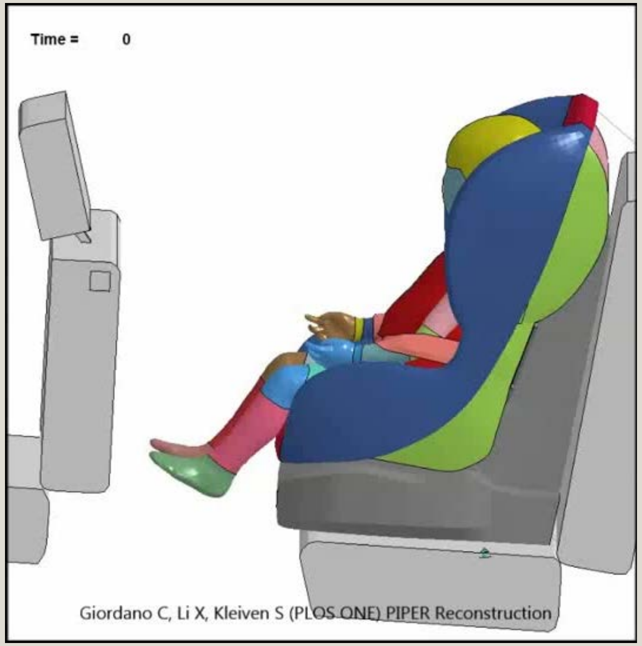
Frame Name (Relative to World Frame)	Angle Value (ry)
	Case 2017
Atlas	-7°
Axis	-7°
Third Cervical Vertebrae	-7°
Fourth Cervical Vertebrae	-7°
Fifth Cervical Vertebrae	-7°
Sixth Cervical Vertebrae	-7°
Seventh Cervical Vertebrae	-7°
Skull	15°
Joint Name	
Left Hip	0°
Right Hip	0°
Left Glenohumeral	-12°
Left Elbow	22°
Left Wrist	0°
Right Glenohumeral	-12°
Right Elbow	22°
Right Wrist	0°
Left Knee	-13°
Left Ankle	0°
Right Knee	-13°
Right Ankle	0°



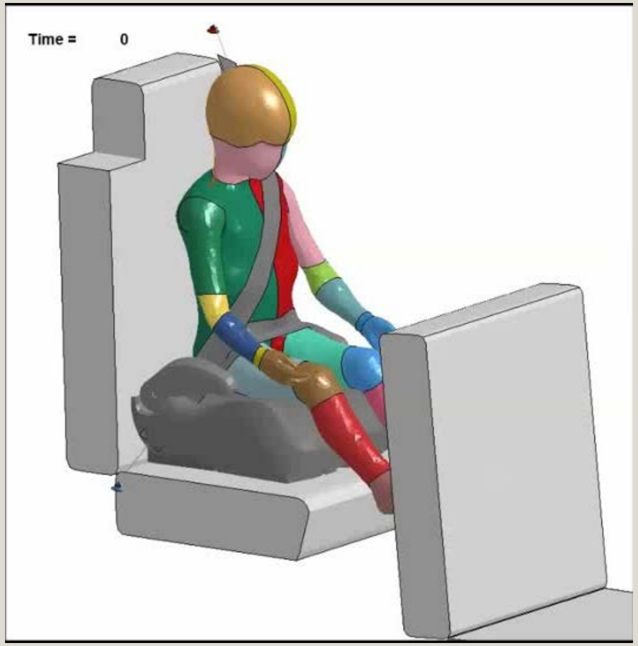


Results: animation

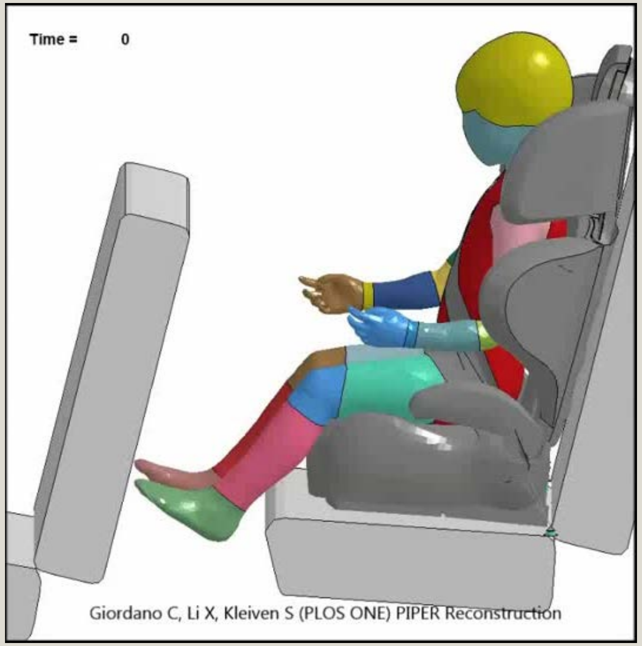
Case 2012



Case 2017



Case 2043

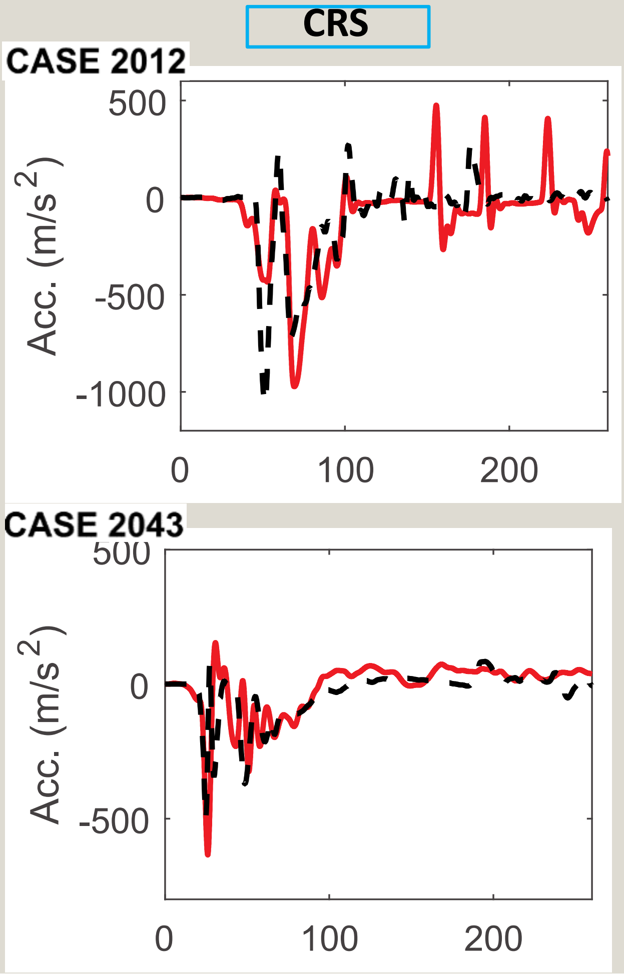


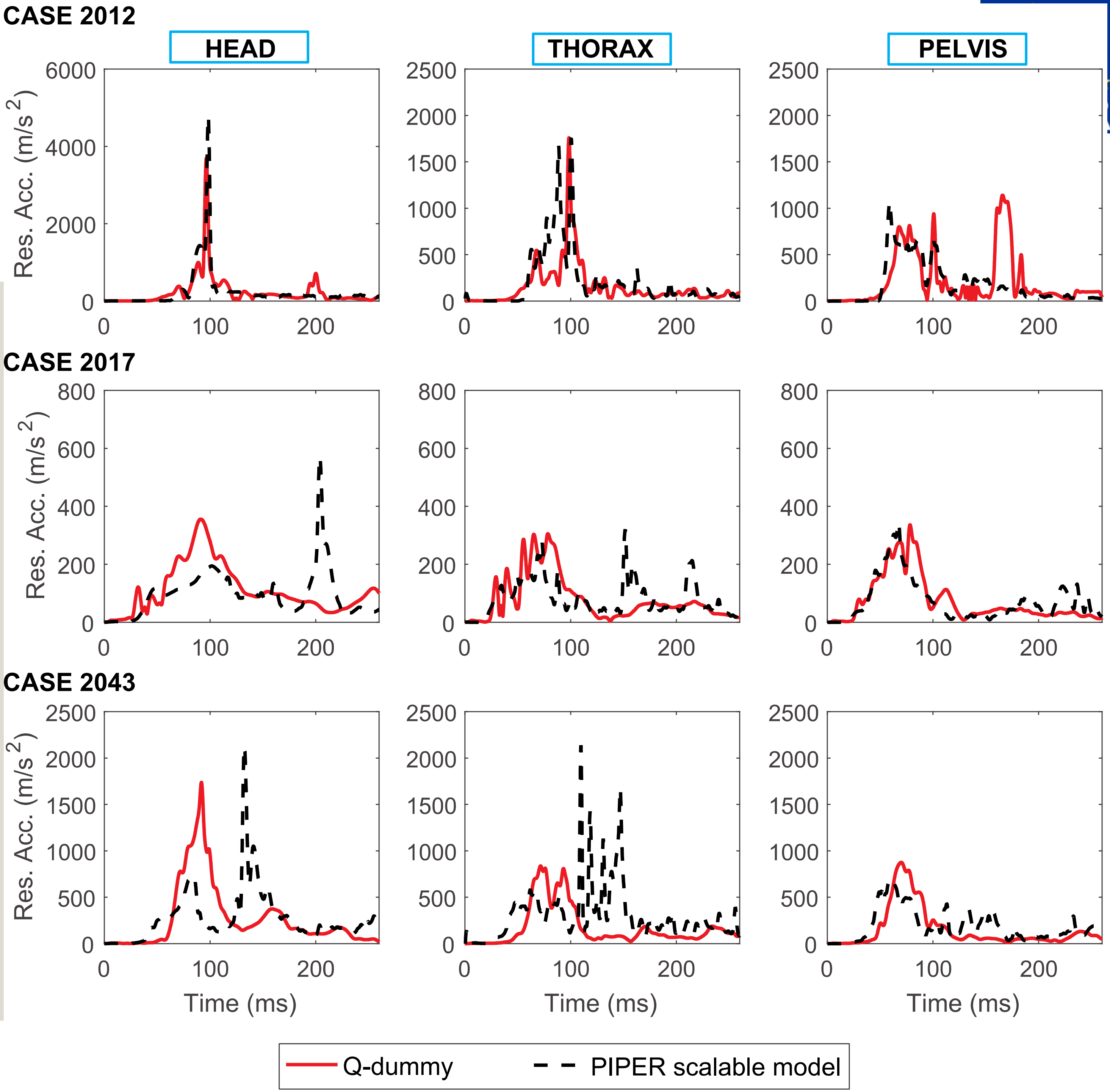

2012


2017

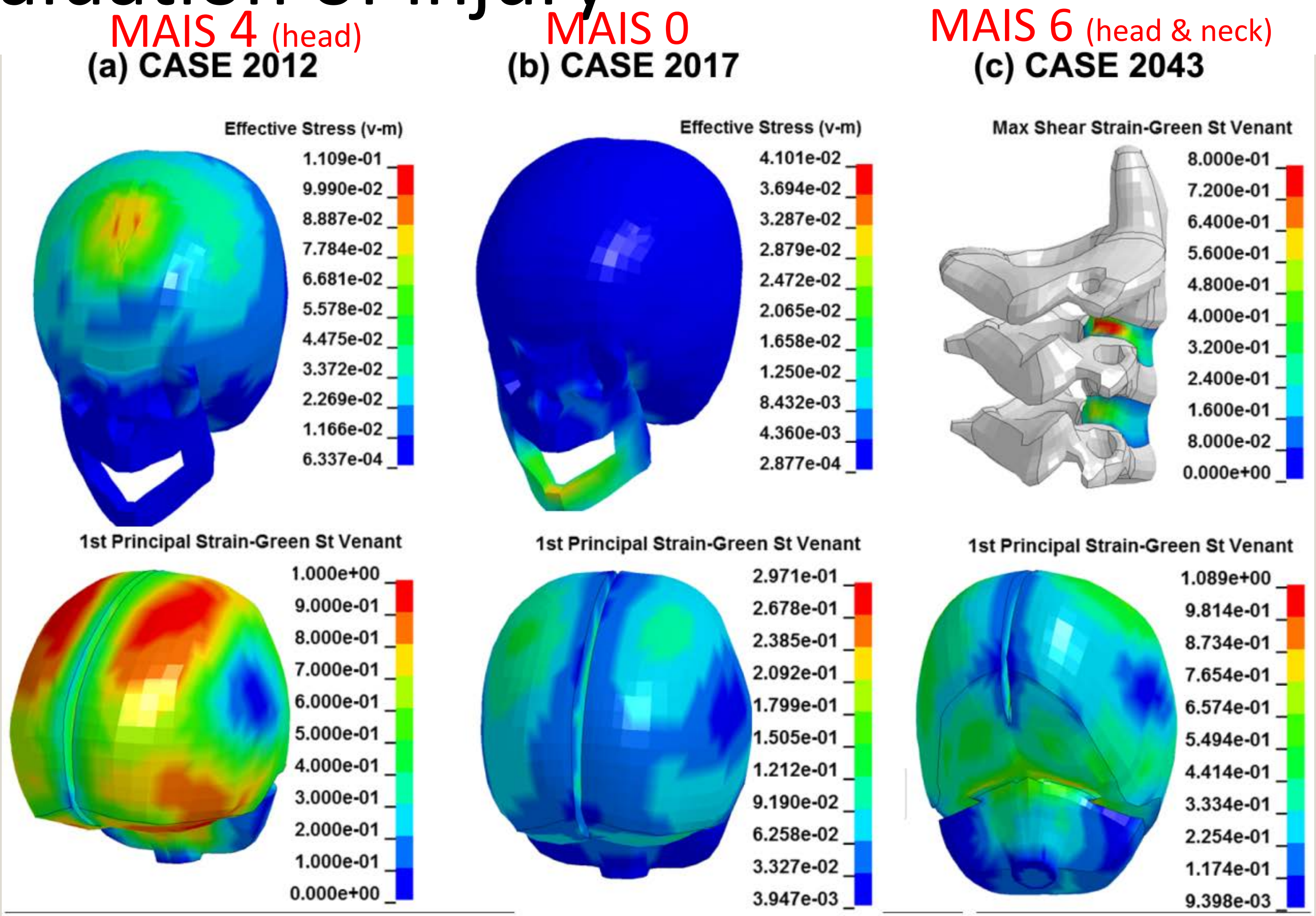

2043

Resultant acceleration





Evaluation of injury



Skull: von Mises stress

Brain: 1st principal strain

Cervical disk: shear strain

Example 4

Application: personalisation of the GHBM Simplified pedestrian to match PMHS tests

Philippe PETIT

Issue: validation of the GHBMC M50 PS

- Set of 18 PMHS tests available (Song et al. 2017)
- Interest for human modelling:
  - Complete anthropometry available (external dimensions + CT-scans)
  - Generic vehicle front ends (sedan, SUV, van)
  - Challenges: precisely account for the specimens anthropometry in order to improve the interaction with the vehicle front end (Kerrigan et al. 2008)
- Several tests by several users @ LAB → feasibility / potential

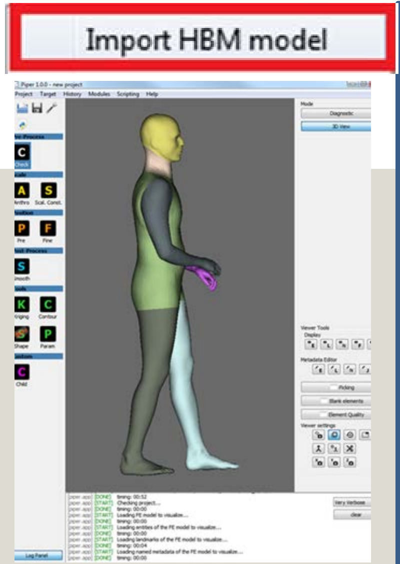
Workflow #1

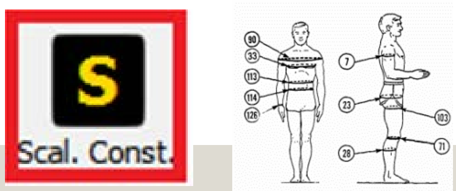
(1) Few measurements ➔ complement using anthropometric database (ANSUR)

(2) correspondence anthro <-> M50-PS ➔ Scaling constraint

(3) Apply target anthro, **Adjust,** and to update scalable model and control points

(4) Scale HBM by Kriging interpolation (control points)

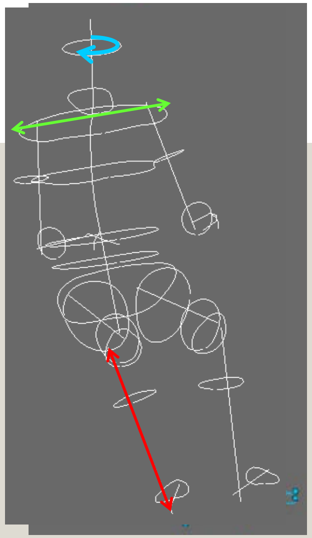


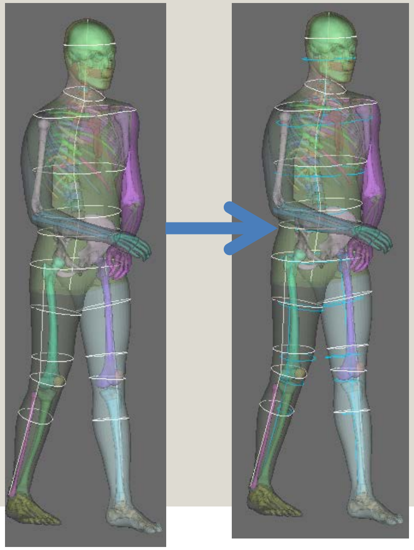


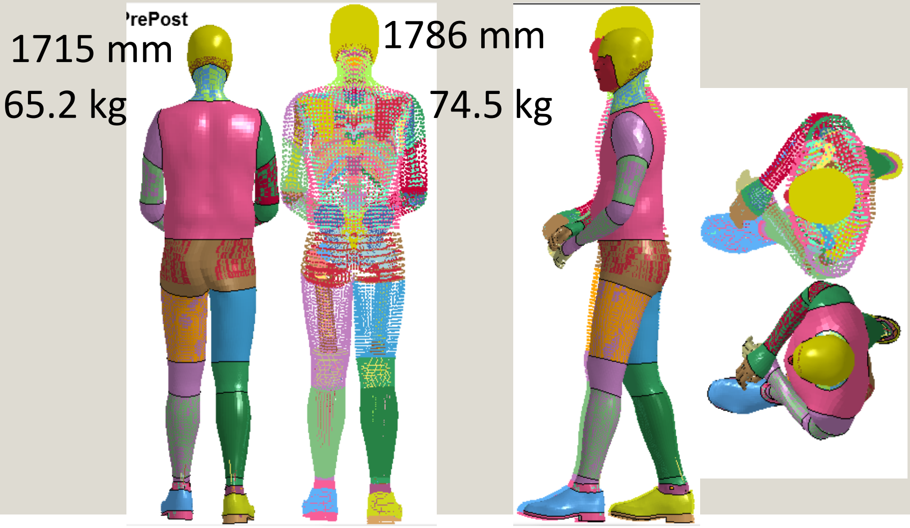
(source: Gordon 1989)

Landmarks+
Hierarchy +
Intersect on skin

Interactive, adjustable, …



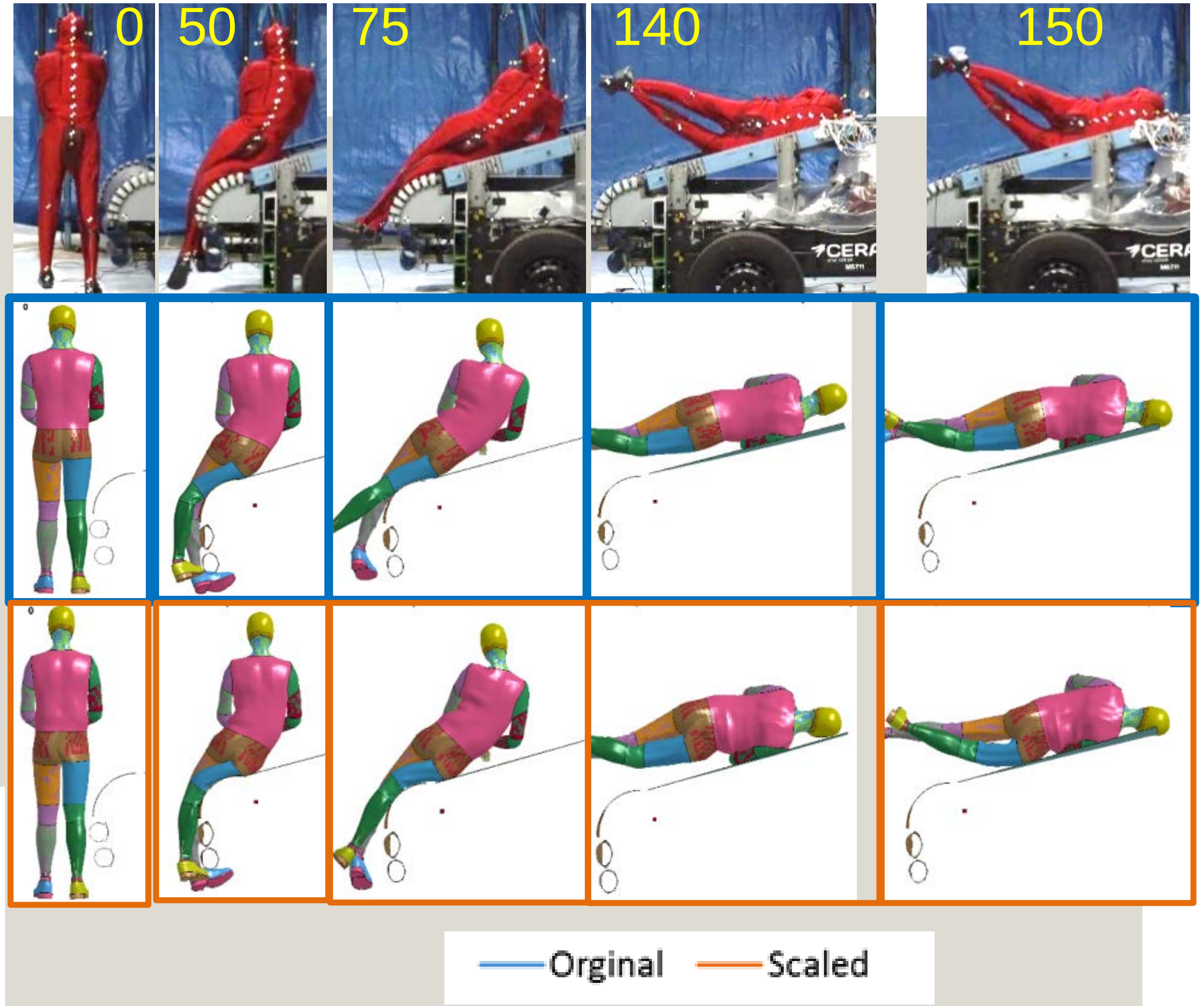


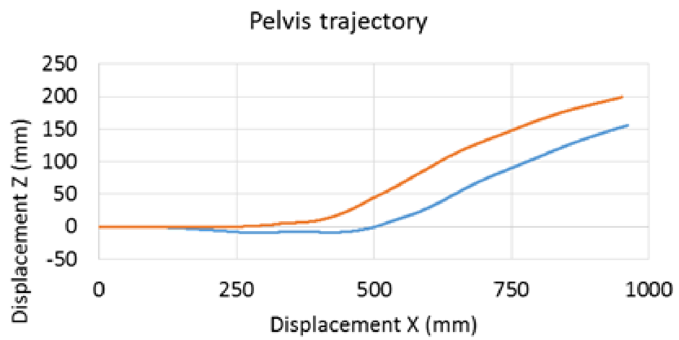


Note: shoes=28mm

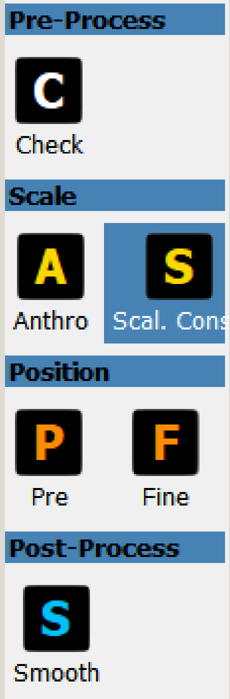
Preliminary results

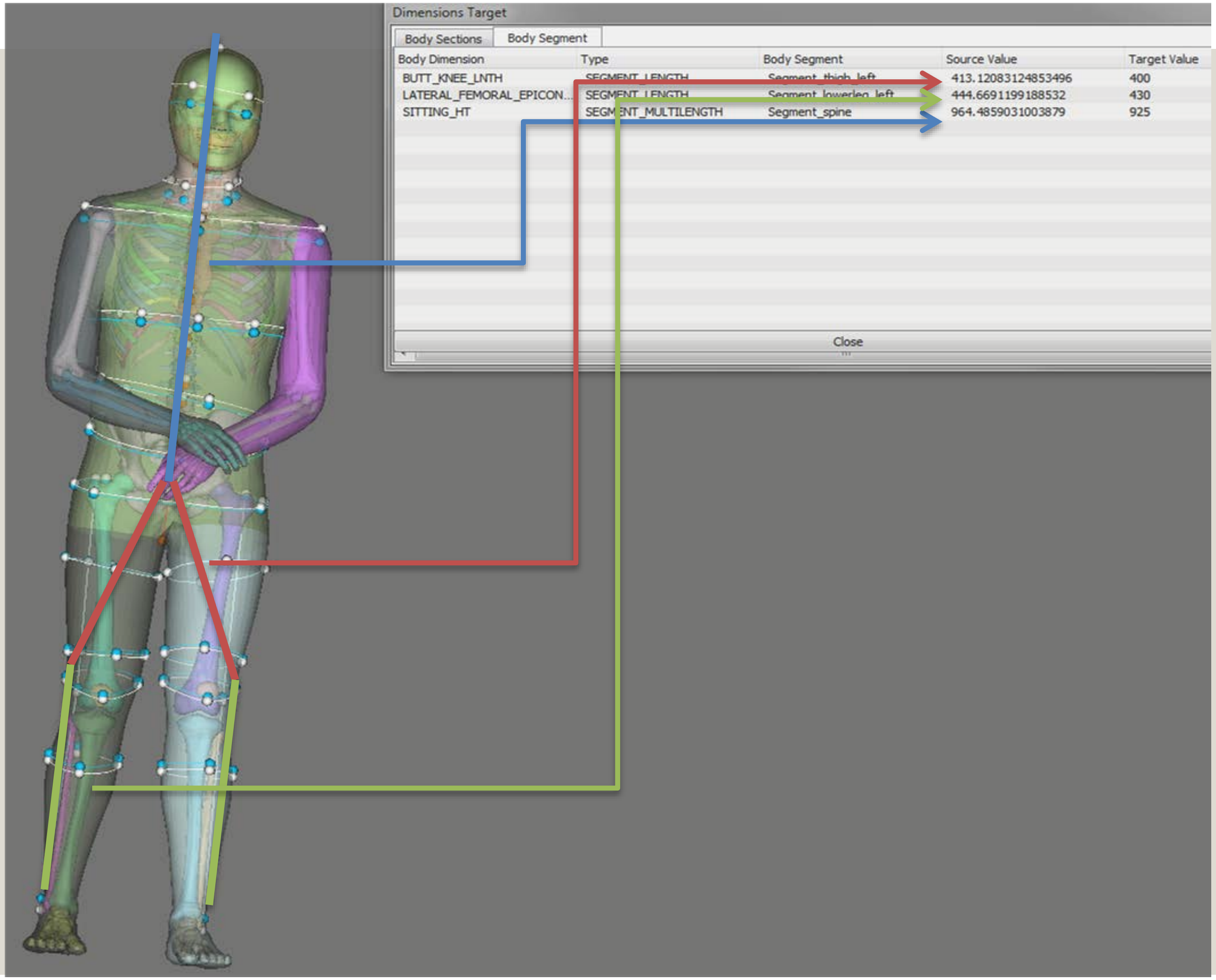
- Models are runnable (no error)
- Similar numerical performance (energy, hourglass, stability…)
- Effect on forces limited
- Effect on kinematics more important (pelvis, point and time of head impact). No velocity change
- Could help study response over a range of stature rather than average.





Workflow #2


Pre-Process
C
Check
Scale
A
Anthro
S
Scal. Cons
Position
P
Pre
F
Fine
Post-Process
S
Smooth


Dimensions Target
Body Sections
Body Segment
Body Dimension
Type
Body Segment
Source Value
Target Value
BUTT_KNEE_LNTH
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400
LATERAL_FEMORAL_EPICON...
SEGMENT_LENGTH
Segment_lowerleg_left
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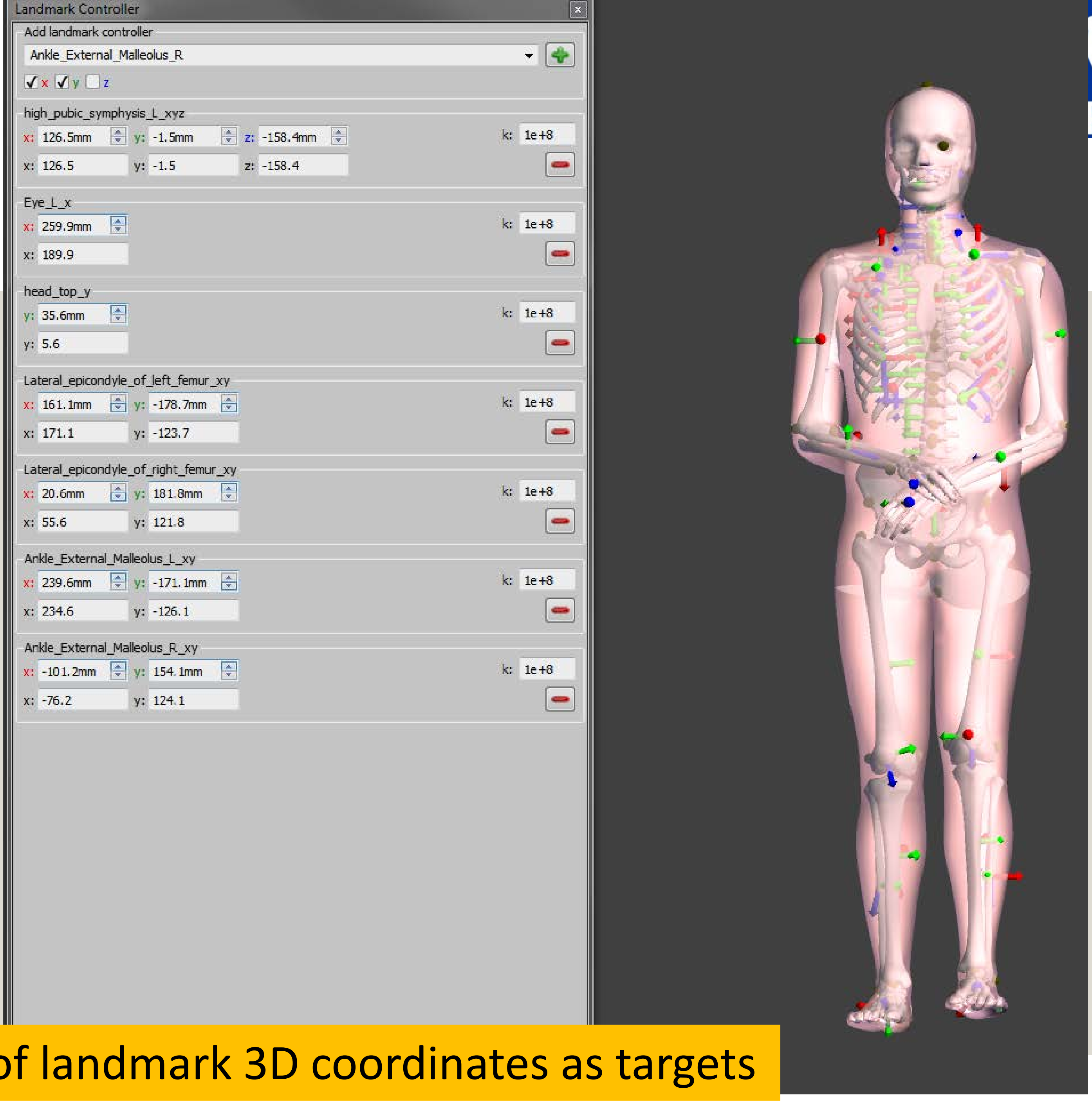
430
SITTING_HT
SEGMENT_MULTILENGTH
Segment_spine
964.4859031003879
925
Close

VDI Wissensforum

Positionning



Use of landmark 3D coordinates as targets

PIPER

Conclusions

- Proof of feasibility
- Several workflows possible
- Documentation to be improved (add examples → contributions are welcome!)

Perspectives

- Duplicate the 18 tests from Song et al. 2017
- Complimentary analysis of the PMHS tests
- Sensitivity study
- Upload all the examples with environment and anthropo info and corresponding model

PIPER Active session

- Examples of recent/ongoing work

1. Obesity and submarining: scaling the GHBMC (P. Beillas)
2. Metadata definition (T. Fuchs, LMU)
3. PIPER Child: Accident reconstructions (P. Petit, for KTH)
4. Pedestrian simulation: the effect of stature (P. Petit, LAB)

- Open discussion…