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road user safety

Validated seated OS-HBM models published on the OpenVT platform and described in scientific papers

WP number: 2
Deliverable: D2.2

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Work package 2, Deliverable D2.2

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Executive summary

As road users come in different sizes, ages, and genders, the aim of WP2 was to create the human body model (HBM) resources used in the VIRTUAL project activities in WP3,4 and 5. Specifically, WP2 has provided a set of HBMs ready for implementation in specified demonstration cases for seated occupants, Vulnerable Road Users (VRUs) and erect passengers in public transport. WP2 has exploited existing HBMs and supporting software previously developed in the national (VIVA) and EU Funded (PIPER) projects. These open-source resources have been further enhanced to extend their application and availability to the community.

The current document reports parts of **Task 2.2: "Seated OS-HBM 50F, OS-HBM 50M, Active-HBM and validation",** mainly belonging to Task 2.2.1, Task 2.2.2 and Task 2.2.3. This report builds on the work reported in milestone M2.2.

In Task 2.2.1 the initially available average female size 50F model from the earlier VIVA project has been further developed and validated for intervertebral kinematics using previously collected volunteer and postmortem human subject (PMHS) data in rear impact conditions. The head and neck response for rear impact has been validated. Different impact directions have been investigated and available validation data have been used to verify occupant kinematics.

In Task 2.2.2 *Injury Detection Systems (IDS)* have been integrated. The VIVA+ family was provided with IDSs for the injury types established for the project as defined in Task 1.2. As whiplash injuries have been identified as a societal problem to be addressed in the project, the upgraded model was developed to assess soft tissue injuries in WP3 using tissue based and dummy based IDSs from Task 1.2. Integration of other relevant IDSs to detect head, chest, and lower extremity injuries have also been incorporated from Task 1.2 for scenarios in WP4 and 5.

In Task 2.2.3 *Scaling and morphing* of the VIVA+ 50F model has been morphed to create a male model – VIVA+ 50M. Using the VIVA+ 50F as a base-model ensures that the male and female are comparable and that future updates can be implemented in both models. The validation of the male model for kinematics and injury prediction has been done by the same approach as for the female model.

A scientific publication of the core content of the present Deliverable (D2.2) is in progress.

1 VIVA+ Seated Open-Source Human Body Models

The main objective of WP2 has been to create scalable open-source human body models of an average female and an average male, the VIVA+ 50F and 50M models, to be used in the project activities in WP3, WP4 and WP5. Specifically, WP2 will provide a set of HBMs ready for implementation in specified demonstration cases for seated occupants, Vulnerable Road Users (VRUs) and erect passengers in public transport. The models developed in VIRTUAL are named VIVA+. The VIVA+ versions have been delivered to the partners repeatedly, adding incremental improvements during the project.

1.1 Task 2.2

The current document reports parts of **Task 2.2: "Seated OS-HBM 50F, OS-HBM 50M, Active-HBM and validation",** mainly belonging to Task 2.2.1, Task 2.2.2 and Task 2.2.3. This report builds on the work reported in milestone M2.2.

1.2 Model Development Workflow

The VIVA+ base-model represents a seated average female. All model development has been carried out on this base-model. The geometry for this model was partly based on statistical shape models, representing the outer skin, the ribcage, the pelvis, the femur and the tibia, and partly based on an average shaped individual. The target stature is 162 cm and the target BMI is 24 corresponding to the average female defined in the same data source as crash test dummies are based on (Schneider et al., 1983). Target age is 50 years old corresponding to the average adult age in the European Union[1] . The workflow is illustrated in Figure 1.

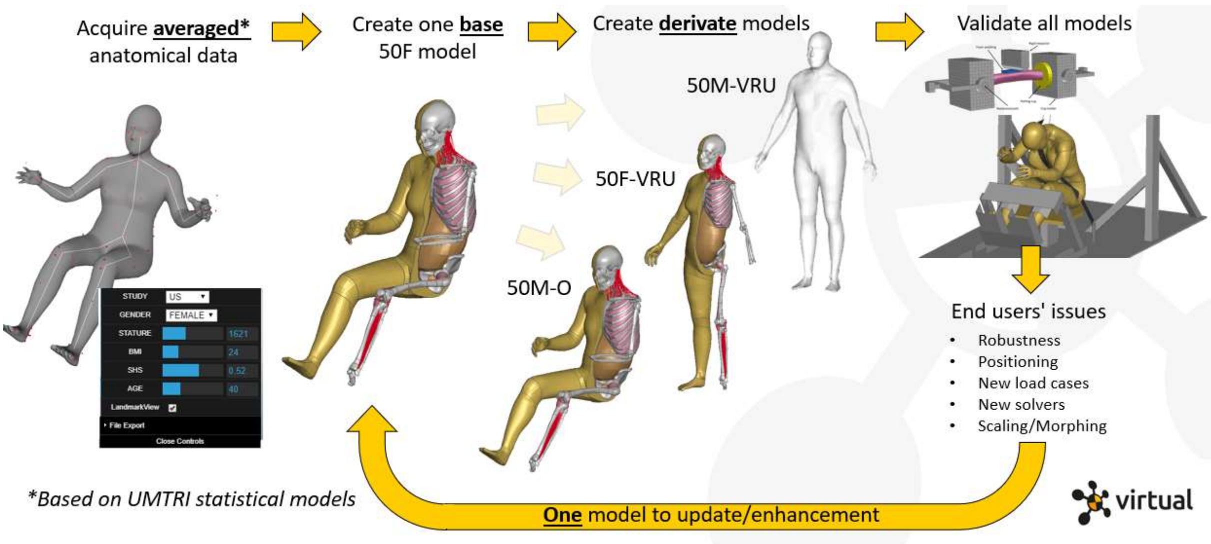

Figure 1. The model development workflow for the VIVA+ models.

Starting from the base-model, derivative models can be created using mesh morphing. Currently, morphing codes to generate the standing average female and the seated average male are available.

[1] https://vivaplus.readthedocs.io/en/latest/model/anthro/

The morphing code for the standing average male is under development. The current VIVA+ model family is shown in Figure 2.

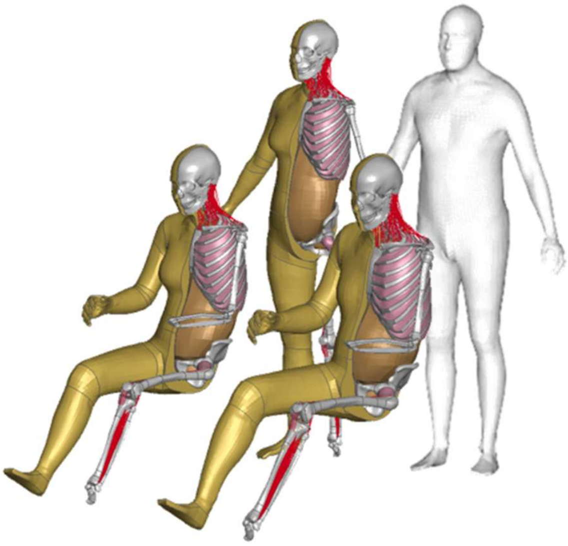

Figure 2. The VIVA+ model family.

All models are validated using appropriate validation load cases. The first level of validation is on component level, e.g., a single rib or an isolated femur. The second level of validation is on full HBM level.
When the models need to be updated or enhanced, this is carried out on the base-model. As the derivative models shares properties with the base-model, all changes are automatically carried over to the derivative models. One benefit with this approach is that this will save time during updates and bug fixes. Another benefit is that this approach minimizes the risk of implementation errors.

1.3 Model development, updates, and enhancements

The VIVA+ models have been continuously improved during the project and several versions have been released as listed in the Table 1. The latest model can be accessed at the model repository: https://virtual.openvt.eu/fem/viva/vivaplus. The current release is v0.2.5 (Download link). The models have been improved in several aspects, including biofidelity, postprocessing, numerical performance and robustness. The numerical improvements include element quality, energy balance, contacts, and material definitions. Examples of improvements are improved thorax contacts and knee ligament pre-stretch for improved biofidelity, and numerical improvements leading to reduced hourglass energy. The material models for the soft tissue have also been revised.

Table 1. List of model releases.

Model version	Release date	Major changes
0.0.1	2020-01-31	Preliminary seated 50F model.
0.1.0	2020-04-30	Added VRU. Joints and ligaments.
0.1.1	2020-06-10	Updates for lungs and spine.
0.1.2	2020-06-10	Neck and skin updates.
0.1.3	2020-06-22	Rib and hip ligament updates.
0.1.4	2020-07-01	Updated PIDs and includes for spine.
0.1.5	2020-07-01	Cortical solid layer in some femur parts.
0.1.6	2020-08-21	Thorax constraints and contacts updates.
0.2.0	2020-09-10	Landmarks for Dynasaur postprocessing.
0.2.1	2020-12-23	Knee ligament prestretch and thorax tiebreak sliding contact.
0.2.2	2021-04-13	Seated male 50M and contact updates.

Model version	Release date	Major changes
0.2.3	2021-06-17	TB024 postures and adding shoes + updated documentation.
0.2.4	2021-07-09	Additional output for injury prediction.
0.2.5	2021-09-22	Improvement of elbow joint and head stiffness Add standing 50M model based on that revision.

The robustness of the models has been improved and evaluated by means of several robustness load cases involving both seated occupants and VRUs as shown in Figure 3. These load cases, which include a generic vehicle interior for the occupant cases and a generic car front for the VRU cases, are used to ensure that the models run to normal termination also for loading of higher severity and that the computed energies are reasonable.

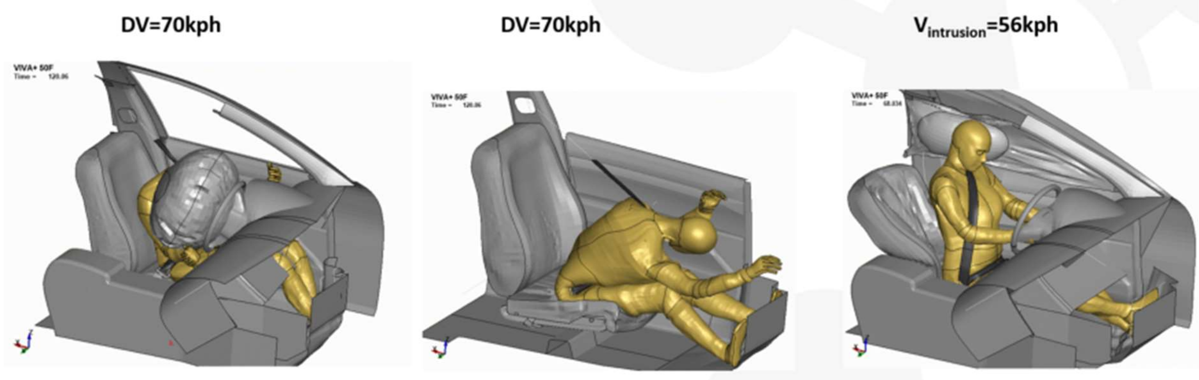

Figure 3. Example of robustness load cases with gerneic vehicle interior.

Validation Catalogue

The models (base-model and derivatives) have been validated both on component level, see Table 2, and on full HBM level, see Table 3. The validated body parts correspond to the body parts identified for the different use cases (WP3 and WP4). The complete list of validation cases can be found at: https://vivaplus.readthedocs.io/en/latest/model/validation/. The publications corresponding to these validations are listed at https://vivaplus.readthedocs.io/en/latest/model/publications/.

The VIVA+ validation catalogue is implemented using a combination of open-source libraries (Dynasaur, Python and Jupyter) and publishing tools (Jupyter book). The computational notebook, Jupyter, was used to implement reproducible post-processing workflows and automated report building for future releases of the VIVA+ models.

Table 2. Validation load cases on Component/Sub-model level

Body region	Author/Year	Validation data	Manuscript
Single rib	Kang et al (2020)	Force/deflection compared to a corridor (females age group 41-60yrs)	VRU
Single rib	Forman et al (2018)	Force/deflection compared to 10 female PMHS tests	Oc
Pelvis	Guillemot et al (1998)	Force/deflection compared to 10 (1F+9M) + 12 (6F+6M) denuded pelvises	VRU
Cervical Spine	Nightinggale et al (2002)	Force/deflection compared to 52 female spinal segments	Oc
Cervical Spine	Wheeldon et al (2006)	Force/deflection compared to 5 male and 2 female PMHS	Oc
Nead/neck	Stemper et al (2004)	Kinematics of head and cervical spine compared to 5 male and 5 female PMHS	Oc

Head/neck	Kang et al (2018)	Kinematics of head and cervical spine compared to 5 male PMHS	Oc
Head	Loyd et al (2014)	Acceleration/time history compared to six male PMHSs	HW / VRU
Proximal Femur	Ariza et al (2015)	Force/time compared to 14 PMHS tests	VRU
Femur shaft	Ivarsson et al (2009)	Force/time compared to 16 PMHS tests	VRU
Tibia	Ivarsson et al (2006)	Force time compared to 40 PMHS tests (4 female)	VRU
Knee	Bose et al (2008)	Moment/valgus angle compared to 18 male and 6 female knee specimens	VRU

Table 3. Validation load cases on Full HBM level

Body region	Author/Year	Validation data	Manuscript
Frontal sled	Crandall (2013+2016)	Whole body kinetics, kinematics and chest deformation compared to two female PMHSs	Oc
Rear sled	Yoganandan et al (2000)	Whole body kinematics compared to four female and one male PMHSs	Oc
Frontal torso hub	Kroell et al (1971)	Force/deflection compared to 15 PMHS (5 female, 10 male)	HW
Frontal torso hub	Viano et al (1989)	Force/deflection compared to 11 male and 3 female PMHS tests	HW
Back torso hub	Viano et al (2001)	Force/deflection compared to 24 PMHS tests with 8 specimens	HW
Frontal torso hub	Forman et al (2015)	Force/deflection compared to 12 tests with 4 male PMHS	HW
Abdominal bar	Hardy et al (2001)	Force/deflection compared to three PMHS tests (1 female +2 male)	HW
Abdominal belt	Ramachandra et al (2016)	Force/deflection compared to two PMHS tests (2 female)	Oc
Shoulder impactor	Compigne et al (2004)	Force/deflection compared to seven PMHS (5 female, 2 male)	HW
Lateral hub many locations	Viano et al (1989)	Force/deflection compared to 11 male and 3 female PMHS tests	HW
Pedestrian impact	Snedeker et al (2005)	Whole body kinematics compared to 2 female and 3 male PMHS	VRU
Pedestrian impact	Paas et al (2015)	Whole body kinematics compared to 4 male one female PMHS	VRU
Pedestrian impact	Forman et al (2015)	Whole body kinematics compared to PMHS corridors derived from tests with 3 male PMHS	VRU
Farside sledtests	Forman at al., (2013)	Whole body kinematics compared to PMHS	Oc
Nearside sledtest	Wood et al., (2013)	Whole body kinetics and kinematics and rib fracture risk compared to PMHS (force, acceleration, time) for 7 males	Oc
Nearside sledtest	Wood et al., (2014)	Whole body kinetics and kinematics and rib fracture risk compared to PMHS (force, acceleration, time) for 6 females	Oc

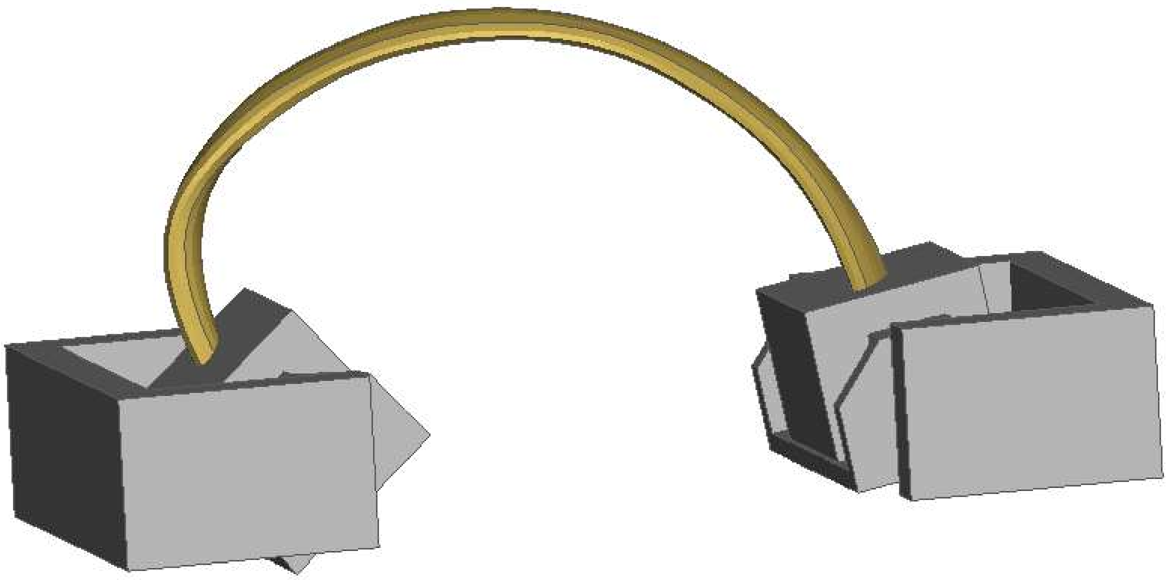

Figure 4. Example of component level validation. 50F Rib 7 from the Kang (2020) anterior-posterior single rib bending validation setup.

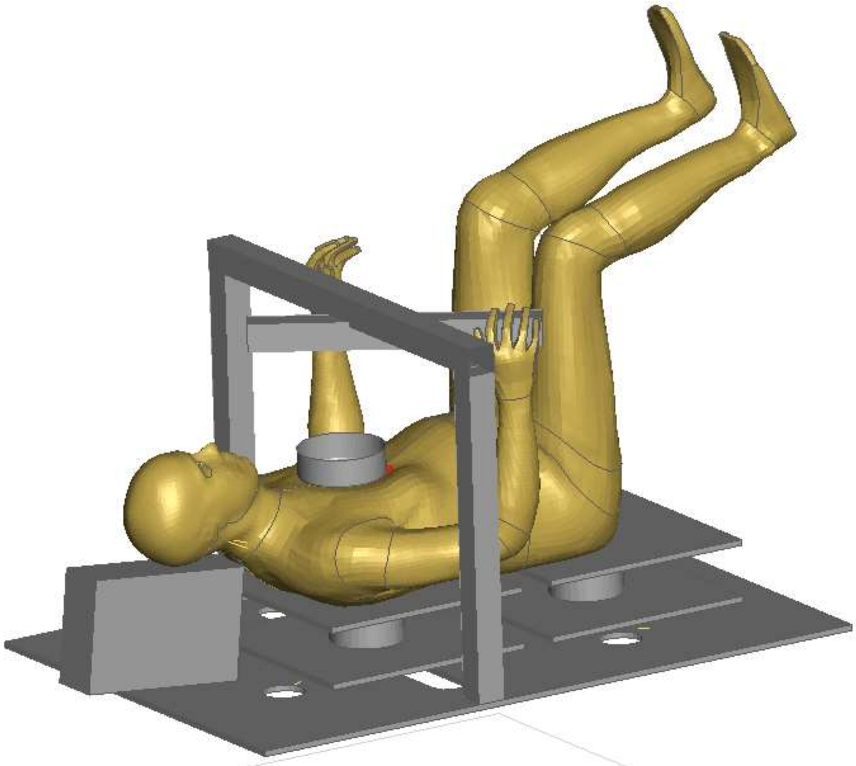

Figure 5. Example of subsystem validation. 50M hub impact from the Kent (2003) validation setup.

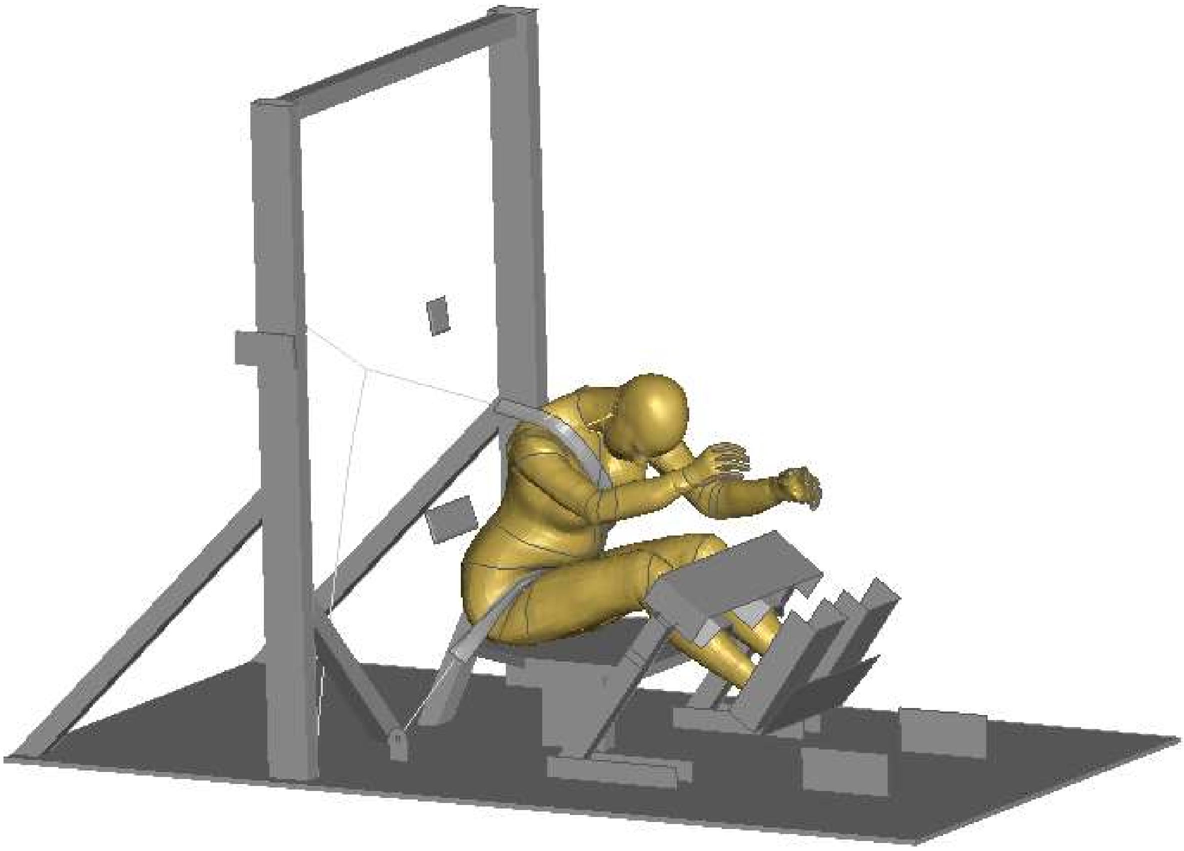

Figure 6. Example of full body validation. 30km/h Gold standard frontal sled impact using the 50F model. Validation setup from Crandall (2013).

1.4 Injury detection systems

Nodal sensors have been included on anatomic landmarks as "injury detection systems", which are shown in Figure 7. By using the nodal histories, acceleration, velocities, trajectories and rotations can be evaluated. Some of the sensors are also used as input for the calculation of injury criteria (e.g., HIC).

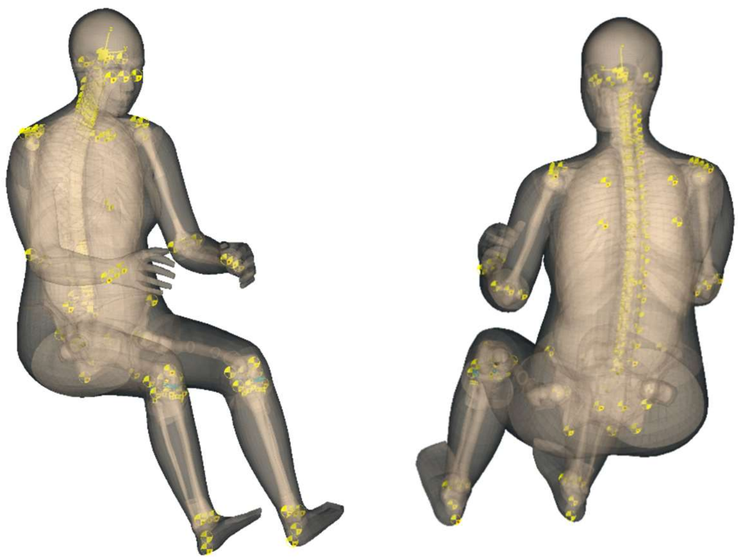

Figure 7. Injury Detection systems shown on the seated 50F VIVA+ model.

Metafiles for harmonised postprocessing for the open-source tool Dynasaur have been developed (dynasuar.def). Calculation procedures for the injury criteria (kinematic and strain-based) were implemented into a calculation_procedure.def file based on the discussions within the WP1 and WP2 partners. The files can be used for all VIVA+ model derivatives, as the IDs of the nodes and part IDs are the same. However, not all criteria are meaningful for all load cases, which is why different calculation procedure files were prepared.
A list of the recommended injury criteria and the "level of trust" is available as part of the Model documentation https://vivaplus.readthedocs.io/en/latest/model/injury-assessment .

1.5 Documentation

With the aim of providing comprehensive and user-friendly documentation, we implemented a web-based open documentation for the VIVA+ models. The documentation files are hosted and version controlled on the same repository as the models. This enables the documentation to be continuously updated along with model releases. The documentation is implemented with open-source Python-based MkDocs library and hosted on ReadTheDocs (https://vivaplus.readthedocs.io/).
The documentation intends to provide tutorials, how-to guides, and technical reference for the VIVA+ models. The current sections include Model Documentation, User Guide, and Contributor Handbook. The Model Documentation provides body region-wise information on finite element implementations. The User Guide and Contributor Handbook sections are intended as learning resources for new users and future contributors, respectively.

1.6 Open-source community engagement

We undertook efforts to promote the VIVA+ models and the Open Science tools and workflows that we are using with the models. We conducted a hands-on workshop in conjunction with the VIRTUAL mid-term workshop held during IRCOBI 2020 conference. This workshop trained future users and potential contributors of VIVA+ models in collaborative model development using git and model postprocessing and reporting using Dynasaur and Jupyter notebooks.
A hackathon was also organized during September-October 2021 to give hands-on tutorials and opportunity to work on the models with the support of the VIVA+ developers. The learning resources we developed for this workshop are openly available (https://viva-workshop.readthedocs.io/, https://vivaplus.gitlab.io/tutorials/intro.html) and can serve as resource for onboarding of future VIVA+ users too.

2 Publications and Presentations

VIRTUAL VIVA+ online Hackathon, 23.9.-14.10.2021, online
https://www.youtube.com/playlist?list=PL7DKxijRQw862BLj6J7tzgz7ATlm1zUt7
https://vivaplus.gitlab.io/tutorials/intro.html
(Workshop presentations with public youtube documentation and tutorials)

Schubert, A.; Erlinger, N.; Leo, C.; Iraeus, J.; John, J.; Klug, C. (2021): Development of a 50th Percentile Female Femur Model; *IRCOBI Conference Proceedings* .
http://www.ircobi.org/wordpress/downloads/irc21/pdf-files/2138.pdf
(Open Access reviewed scientific conference paper)

John, J; Iraeus, J.; Svensson, M; (2021) "A framework for continuous integration in human body finite element model lineup", 28th Congress of International Society of Biomechanics, Abstract id : 5093219, July 2021, Stockholm, Sweden
(https://www5.shocklogic.com/scripts/jmevent/programme.php?Client_Id=%27KONGRESS%27&Project_Id=%2721349%27&System_Id=1)
(Conference presentation with public available abstract)

Klug, C. Iraeus, J., John, J.; Svenning E.; Kranjec M.; Svensson M.; Leo, C.; Schubert, A.; Linder, A. (2020): Introduction of the VIVA+ Vulnerable Road User Models; *carhs conference on Human Modeling and Simulation in Automotive Engineering*, 20.11.2021, online. https://projectvirtual.eu/wp-content/uploads/2020/11/2020-11-20_Klug_et_al_VIVAVRU.pdf
(Conference presentation with public slides)

John, J; Iraeus, J.; Svensson, M; Klug, C; Linder, A; (2020) "VIVA+ Open Human Body Models for Virtual Testing" Automotive CAE Grand Challenge, Hanau, Germany
(Conference presentation with public power point documentation)
http://dx.doi.org/10.13140/RG.2.2.20725.29928

Presentation of WP2 on the VIRTUAL-OSSCAR workshop, 08.09.2020, online
https://projectvirtual.eu/wp-content/uploads/2020/09/03-Johan_VIRTUAL-OSCCAR-Workshop-WP2-Sep-2020_rev1.pptx,
(Workshop presentation with public power point documentation)

Workshop "Introduction to the VIVA+ models and OpenVT Platform", 10.09.2020, online.
https://youtu.be/N83d7zUBgB0
(Workshop presentation with public youtube documentation)

3 References

Schneider, L. W., Robbins, D. H., Pflug, M. A., & Snyder, R. G. (1983). *Development of Anthropometrically-based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family, Volume 1*.