SAFETY ENHANCED INNOVATIONS FOR OLDER ROAD USERS (SENIORS): FURTHER DEVELOPMENT OF TEST AND ASSESSMENT PROCEDURES TOWARDS AN IMPROVED PASSIVE PROTECTION OF PEDESTRIANS AND CYCLISTS

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ABSTRACT

Test and assessment procedures for passive pedestrian protection based on developments by the European Enhanced Vehicle-safety Committee (EEVC) have been introduced in world-wide regulations and consumer test programmes, with considerable harmonization between these programmes. Nevertheless, latest accident investigations reveal a stagnation of pedestrian fatality numbers on European roads running the risk of not meeting the European Union's goal of halving the number of road fatalities by the year 2020. The branch of external road user safety within the EC-funded research project SENIORS under the HORIZON 2020 framework programme focuses on investigating the benefit of modifications to pedestrian test and assessment procedures and their impactors for vulnerable road users with focus on the elderly.

Injury patterns of pedestrians and cyclists derived from the German In-Depth Accident Study (GIDAS) show a trend of AIS 2+ and AIS 3+ injuries getting more relevant for the thorax region in crashes with newer cars (Wisch et al., 2017), while maintaining the relevance for head and lower extremities. Several crash databases from Europe such as GIDAS and the Swedish Traffic Accident Data Acquisition (STRADA) also show that head, thorax and lower extremities are the key affected body regions not only for the average population but in particular for the elderly. Therefore, the SENIORS project is focusing on an improvement of currently available impactors and procedures in terms of biofidelity and injury assessment ability towards a better protection of the

affected body regions, incorporating previous results from FP 6 project APROSYS and subsequent studies carried out by BASt. The paper describes the overall methodology to develop revised FE impactor models.

Matched human body model and impactor simulations against generic test rigs provide transfer functions that will be used for the derivation of impactor criteria from human injury risk functions for the affected body regions. In a later step, the refined impactors will be validated by simulations against actual vehicle front-ends. Prototyping and adaptation of test and assessment procedures as well as an impact assessment will conclude the work of the project at the final stage.

The work will contribute to an improved protection of vulnerable road users focusing on the elderly. The use of advanced human body models to develop applicable assessment criteria for the revised impactors is intended to cope with the paucity of actual biomechanical data focusing on elderly pedestrians. In order to achieve optimized results in the future, the improved test methods need to be implemented within an integrated approach, combining active with passive safety measures.

In order to address the developments in road accidents and injury patterns of vulnerable road users, established test and assessment procedures need to be continuously verified and, where needed, to be revised. The demographic change as well as changes in the vehicle fleet, leading to a variation of accident scenarios, injury frequencies and injury patterns of vulnerable road users are addressed by the work provided by the SENIORS project, introducing updated impactors for pedestrian test and assessment procedures.

INTRODUCTION

Test and assessment procedures for passive pedestrian protection which are based on developments by the European Enhanced Vehicle-safety Committee (EEVC) have been introduced more than a decade ago within and harmonized to a large extent between world-wide regulations such as GTR9 (2009) and consumer test programmes like Euro NCAP (2016). Despite continued improvements to passive vehicle safety of passenger cars, latest accident investigations resulted in a stagnation of pedestrian fatality numbers on European roads, facing the risk of not meeting the European Union's goal of halving the number of road fatalities by the year 2020. The EC-funded research project SENIORS under the HORIZON 2020 framework programme is developing modified pedestrian test and assessment procedures and impactors with the aim to improve passive pedestrian safety, also addressing the particular safety needs of cyclists, with special focus on the elderly. In-depth accident studies investigate the injury severity of the mostly affected body regions of vulnerable road users to figure out relevant fields of action. Current pedestrian impactors are analyzed regarding their ability to address recent accident scenarios, and are subsequently modified, where possible. Remaining open gaps are closed by the description of new impactor concepts. A simulation matrix is being established and paired simulations with human body models and impactor models against generic test rigs will be performed in order to generate correlations and transfer functions that can be used for existing and new injury criteria. In the next phase of the project which is still running until May 2018, improved pedestrian impactors will be prototyped and tested against modified test and assessment procedures.

ACCIDENT STUDIES AND INJURY PATTERNS

A recent in-depth investigation of road accidents in Germany show the injury severity of different vulnerable road user body regions as a consequence of collisions with passenger cars. As illustrated in figure 1, the study indicates the consistent relevance of severe pedestrian head and leg injuries (AIS 2+ and AIS 3+) in collisions with passenger cars registered between 1995 and 2005 and between 2006 and 2013 respectively. Additionally, two body regions get into the focus of interest. First one is the pelvis area with 14.9 percent of all AIS 2+ injuries and of 23.3 percent of all AIS 3+ injuries. The second body region with an increased percentage of severe injuries is the thorax, having 17.2 percent of all AIS 2+ injuries and 26.7 percent of all AIS 3+ injuries. Therefore, in terms of AIS 3+ pedestrian injuries, the thorax is the most relevant body region, followed by head and pelvis (23.3 percent each) and lower extremities (20 percent).

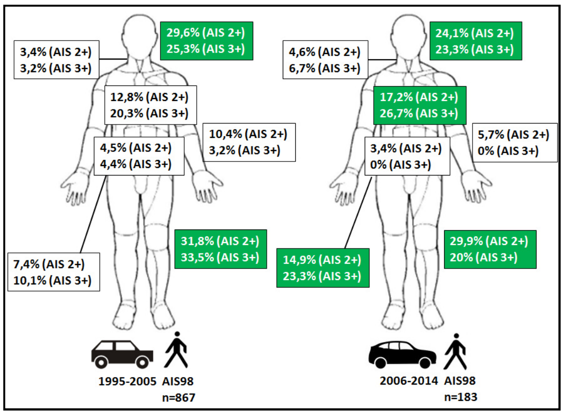

Figure 1: Injury patterns occurring in vehicle to pedestrian collisions according to AIS98 code based on body parts. The Figure shows the relations between the injury severity from AIS 2 (or AIS 3 respectively) to AIS 6 (i.e. AIS 2+ or AIS 3+ respectively) in the particular body region and AIS 2+ (AIS 3+) injury severities of all body regions (Zander et al., 2015).

A similar trend can be observed when looking at the bicyclists as the second big group of vulnerable road users. Here, as depicted in figure 2, the relevance of head and leg injuries is nearly unchanged in terms of AIS 2+ injuries. For AIS 3+ injuries, both areas show a decrease of approximately 5 and 6 percent, respectively. Similar to the pedestrians, the thorax area demonstrates an increased importance regarding AIS 2+ as well as AIS 3+ injuries. Altogether, focusing on AIS 3+ injuries, the lower extremities are the most relevant body region (34.1 percent), followed by the thorax (31.7 percent) and the head (17.1%). Also for AIS 2+ injuries, these body regions remain the mostly affected ones.

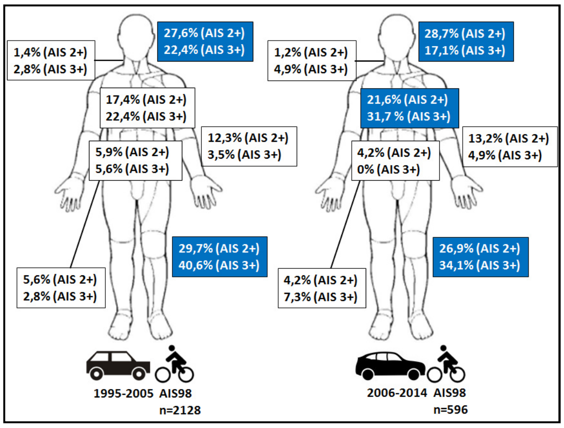

Figure 2: Injury patterns occurring in vehicle to cyclist collisions according to AIS98 code based on body parts. The Figure shows the relations between the injury severity from AIS 2 (or AIS 3 respectively) to AIS6 (i.e. AIS 2+ or AIS 3+ respectively) in the particular body region and AIS 2+ (AIS 3+) injury severities of all body regions (Zander et al., 2015).

One main focus of the SENIORS project is the consideration of the safety needs of older road users. Therefore, based on German and Swedish crash data from GIDAS and STRADA, the percentages of AIS1, AIS2, and AIS 3+ injuries to the different body regions of the age groups 25-64 and 65+ are displayed in figure 3 for pedestrians and in figure 4 for cyclists. Both databases get to the same conclusions regarding the mostly affected body regions for pedestrians and cyclists and their particular relevance for the elderly. When looking at the pedestrian injury levels, head, thorax, pelvis and lower extremities remain the most relevant body regions with the highest portions of AIS2 and AIS 3+ injuries. Furthermore, it is obvious that the elderly suffer more frequently from severe injuries than younger pedestrians.

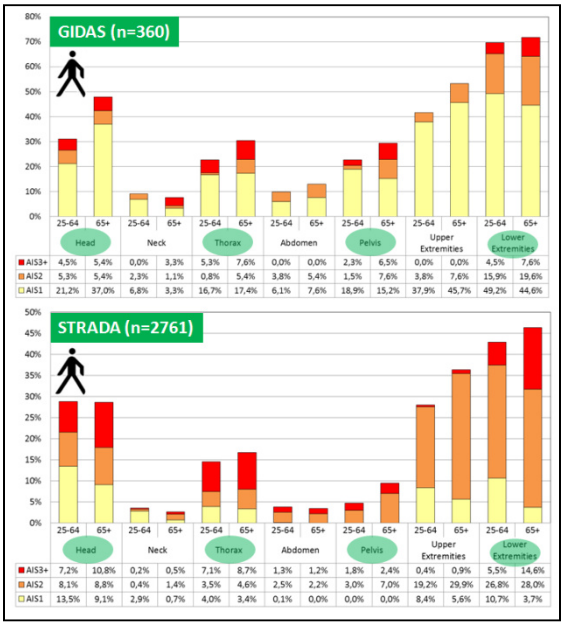

Figure 3: Percentages of injury severities for the different pedestrian body regions within GIDAS and STRADA. Each column adds up to 100 percent by adding all percentages from AIS0 to AIS9. (Wisch et al., 2016).

Injuries to bicyclists show the highest injury levels for the head, the thorax and the lower extremities being the key affected body regions for both age groups.

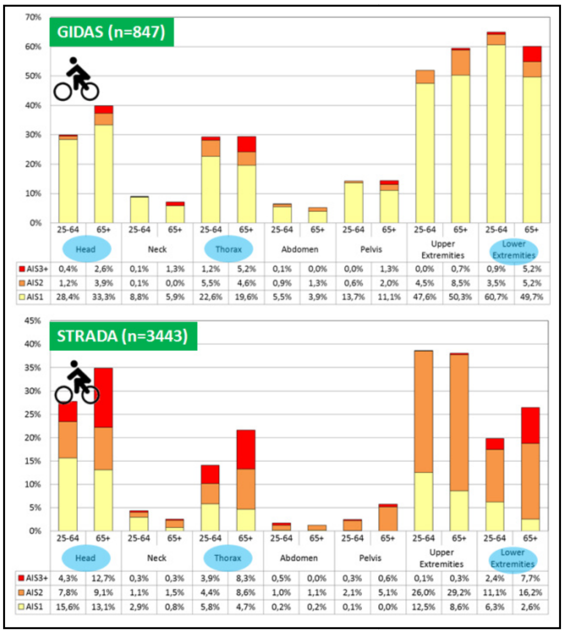

Figure 4: Percentages of injury severities for the different bicyclist body regions within GIDAS and STRADA. Each column adds up to 100 percent by adding all percentages from AIS0 to AIS9. (Wisch et al., 2016).

In-depth investigations of the German GIDAS and Swedish STRADA data is showing the thorax nowadays representing a higher percentage of severe injuries for both groups of vulnerable road users, pedestrians and cyclists. Meanwhile, the importance of head and lower extremity injuries is remaining in most cases at the same level as previously. Furthermore, injury severities of the elderly as vulnerable road users especially in the described body regions are higher than for the age group between 25-64 years. It thus can be concluded, that the main focus in the revision and further development of impactors and test procedures needs to be settled to the head, the thorax and the lower extremities.

METHODOLOGY AND WORKFLOW

Recent accident data resulted in the head, the thorax and the lower extremities being the mostly affected body regions in accidents with vulnerable road users being impacted by passenger cars. Therefore, the external road user branch of SENIORS is focusing on the improvement and development of impactors representing these body regions and the definition of test and assessment procedures with a special focus on the elderly.

Head

Previous studies revealed limitations of the ISO 3.5 kg and 4.5 kg child and adult headform impactors currently used within type approval procedures such as UN-R 127 (2013) as well as consumer test programmes like Euro NCAP (2016). In particular, partly high impactor rotations during impacts on angled or curved vehicle surfaces as depicted in figure 5 lead to sometimes very unrealistic results in terms of linear accelerations and calculated values for the head injury criterion HIC.

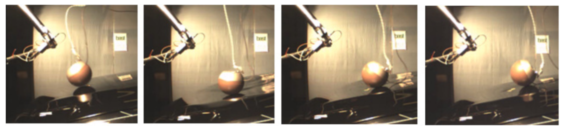

Figure 5: Head impactor rotation during impact on vehicle front (Zander et al., 2016).

Several proposals of a headform impactor with added neck mass have been developed within the EC-funded FP6 project APROSYS (Advanced Protection Systems), sometimes bringing the simulation results for both linear as well as angular acceleration much closer to the outputs of the corresponding human body model, see an example in figure 6:

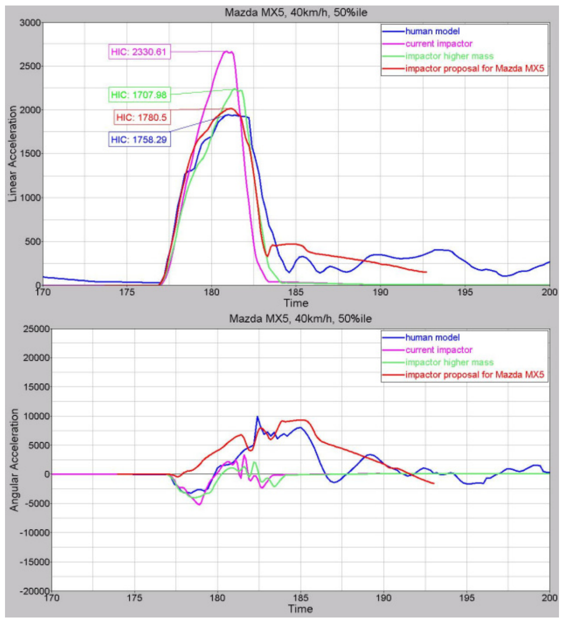

Figure 6: Comparison of the loadings of a 50th human model head and different impactors in the event of a crash with a roadster at 40 km/h (Brüll et al., 2009).

To further follow one of the different approaches, a headform impactor with an attached HIII neck as a possible realization in hardware, having a very good correlation with the human model during roadster impact, was prototyped and tested on a sedan vehicle, with significantly improved results in terms of kinematics, showing a moderate picture of deformation and reasonable loadings, comparable to those of the human model, see figure 7:

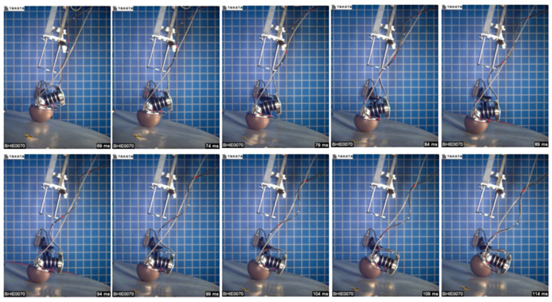

Figure 7: Impactor performance during bonnet impact (Brüll et al., 2009).

For the prototype, a HIII neck with additional mass was attached to a 4.8 kg headform impactor developed by EEVC, that was also used during the first phase of Regulation (EC) No. 78/2009. The total mass of the head neck impactor (HNI) is 7.79 kg, see figure 8:

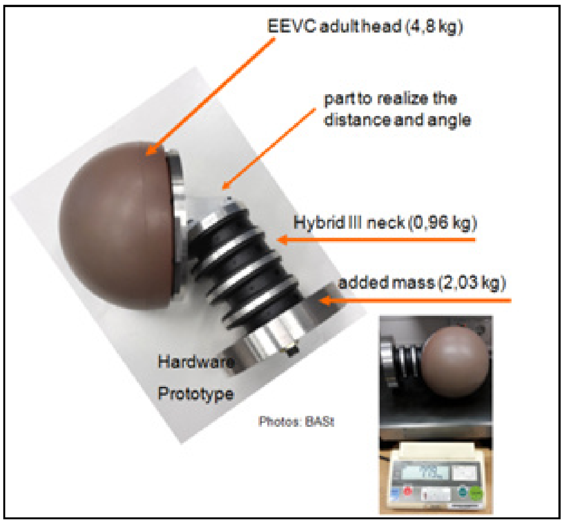

Figure 8: APROSYS head neck impactor HNI.

Within SENIORS, the HNI was used as a basis for simulation to start with. Here, impactor simulations using the 3.5 kg and 4.5 kg ISO impactors were performed against three vehicle front shapes representing different vehicle categories (Sedan, SUV, Van/MPV) and the results compared to those obtained with a modified HNI, using the ISO impactors instead of the EEVC adult head, and full human body model simulations. During the impactor fine tuning, needed modifications to the impactors are aimed to be implemented. Correlation studies between human body model simulations and the finalized impactors will aim at delivering transfer functions that, in the end, can be used for modified impactor risks curves and limits. The results will be validated against human body model simulations to actual vehicle models. An overview of the workflow for developing the HNI is depicted in figure 9:

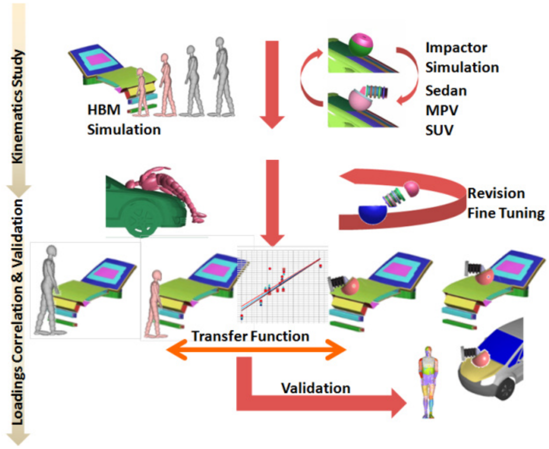

Figure 9: Workflow for HNI modification.

Thorax

No impactor test procedures are currently in use that are related to the injury assessment of thoracic injuries of external road users. On the other hand, Fredriksson et al. (2007) concluded that side impact dummies with good measurement capabilities for the chest and abdomen area could be used for the evaluation of pedestrian impacts to the bonnet leading edge of cars with high front shapes such as SUVs, see figure 10. The assessment could be done using the injury criteria and risk curves for the side impact.

Figure 10: Sled test setup with ES-2-dummy and vehicle buck (Fredriksson et al., 2007).

Based on these findings, as a starting point in the SENIORS project, the torso of the ES-2 model as shown in figure 11 was uncoupled and isolated from the dummy in order to be used as an injury prediction tool during pedestrian component tests.

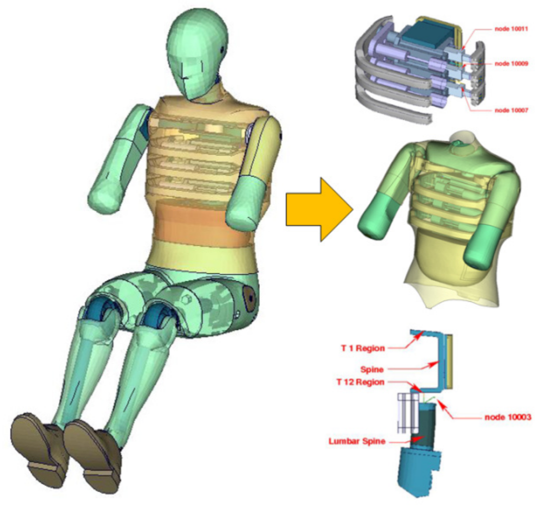

Figure 11: Reduced ES-2 dummy model and nodes for rib intrusions, rib accelerations and lower spine accelerations.

Within SENIORS, simulations with the uncoupled ES-2 torso, named thorax injury prediction tool (TIPT), were performed against the three vehicle front shapes already used during the development of the HNI and the results compared to full human body simulations using THUMS (Total Human Model for Safety). In the next step, tool revision and fine tuning is done for improving the correlation between TIPT and THUMS kinematics and loadings. Aim is the development of transfer functions and injury criteria for the TIPT that will be validated by THUMS simulations against actual vehicle models in the last step. The general workflow for the development of the thorax injury prediction tool is illustrated in figure 12:

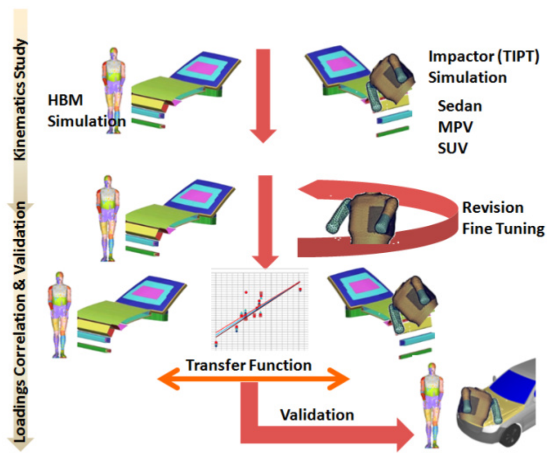

Figure 12: Workflow for TIPT development.

Lower extremities

The third affected body region of vulnerable road users SENIORS is focusing on are the lower extremities. The flexible pedestrian legform impactor (FlexPLI) as the surrogate currently used within vehicle type approval procedures and consumer information programmes for assessing injuries to the lower extremities of pedestrians shows limitations of its biofidelity in particular for the femur area. Therefore, based on human body model simulations, an upper body mass (UBM) representing the pedestrians' torso was developed within the APROSYS project (Bovenkerk et al., 2009). During testing, the FlexPLI with UBM already showed improved kinematics during the impact on modern vehicle fronts. A study carried out by Zander et al. (2011) compared impact kinematics and loadings of the Baseline FlexPLI, the FlexPLI-UBM and the FlexPLI attached to a Hybrid-II 50th male dummy when tested against different actual vehicle frontends (Sedan, SUV, and One Box) and found in most cases good correlations of kinematics and loadings between the FlexPLI-UBM and the FlexPLI attached to the Hybrid-II dummy for all lower extremity regions, as demonstrated in figures 13 and 14. Thus, a first step towards the appropriate assessment of femur injuries was taken.

Figure 13: Correlation of impact kinematics between FlexPLI, FlexPLI-UBM and FlexPLI-HII (Zander et al., 2011).

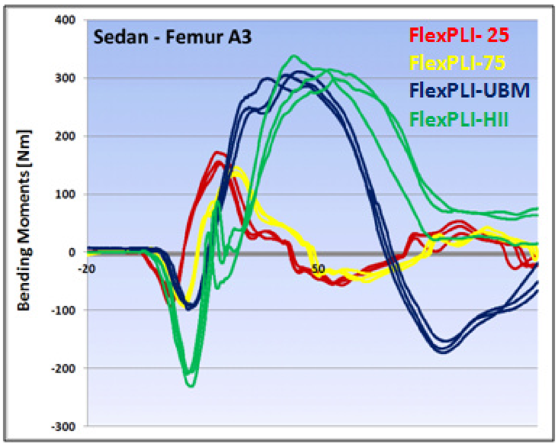

Figure 14: Correlation of loadings vs. time between FlexPLI, FlexPLI-UBM and FlexPLI-HII (Zander et al., 2011).

For the UBM prototype, a 0.25 kg aluminium upper plate, a 2.3 kg steel slide rail and a 4.1 kg aluminum mass were assembled in such a way, that the center of gravity of the prototype was adjustable in four different positions:

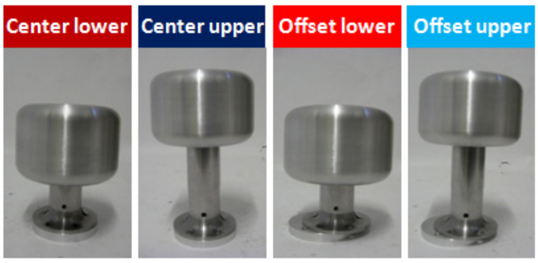

Figure 15: Upper body mass for FlexPLI with four positions for the center of gravity (Bovenkerk et al., 2009).

Simulations within SENIORS started with the FlexPLI-UBM developed in APROSYS against a generic test rig representing four different vehicle categories (Sedan, SUV, Sports Car and Van/MPV) and correlated the results against full human body model simulations with THUMS. A revision of the test method and fine tuning of the impactor is aimed at improving the correlations, establishing transfer functions and define modified injury criteria for the FlexPLI-UBM. In the next step the impactor will be validated against THUMS simulations vs. actual vehicle models. The principle of the development phases are outlined in figure 16:

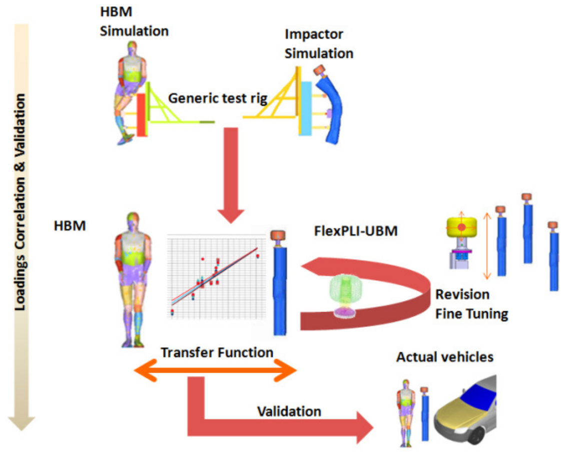

Figure 16: Workflow for FlexPLI-UBM development.

SIMULATION PROGRAMME

In order to compare kinematics as well as loadings of the modified or new impactor models and establish correlations and transfer functions, an extensive simulation programme was carried out by the partners of SENIORS.

Head neck impactor

Human body model simulations using the MADYMO family (6YO, 5th female, 50th male, 95th male) were carried out at vehicle speeds of 40 km/h using the SAE Buck representing the vehicle categories Sedan, SUV and MPV as described by Pipkorn et al. (2012) and illustrated in figures 17 and 18:

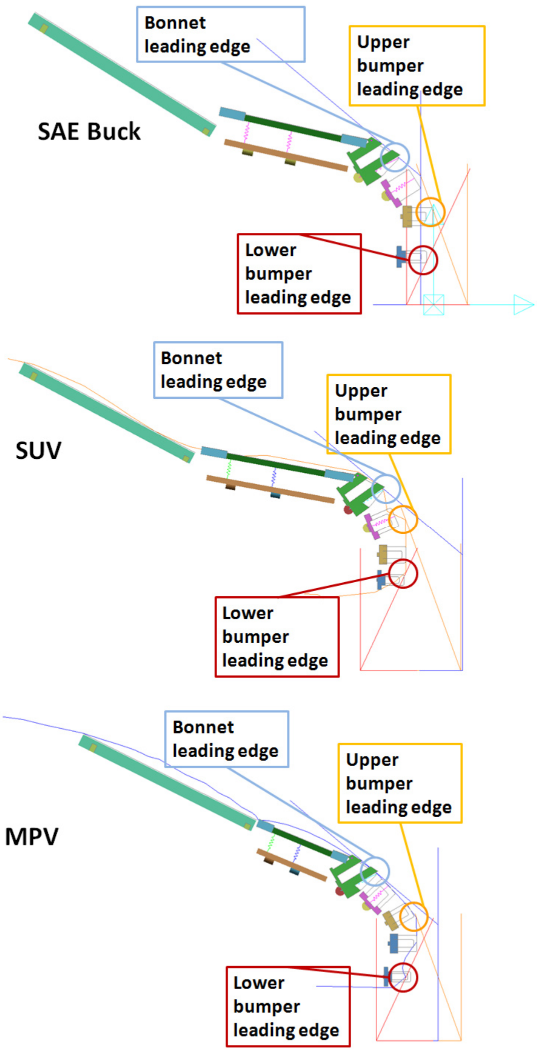

Figure 17: Shape and load paths of SAE Buck (Sedan) and its derivatives.

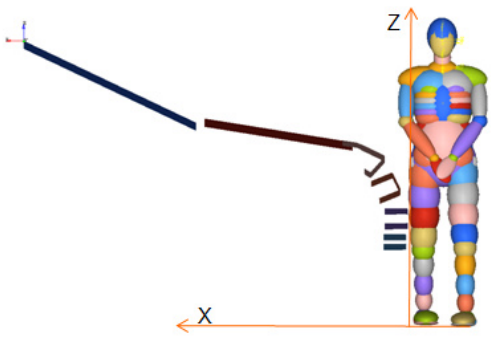

Figure 18: Impact conditions for MADYMO 50th male pedestrian against SUV Buck.

Simulations with the ISO child and adult headform impactors with and without added neck mass were also conducted against the rig. In the first loop of impactor simulations both, head and neck orientation as well as head impact angles were replicated according to the kinematics of MADYMO during the impact.

In many cases, in particular for the larger statures and the MPV buck with shorter bonnet, the head impact occurred in the windscreen area, where due to the windscreen being replaced by alternative material, an assessment of the loading was not convenient. On the bonnet, peak resultant accelerations and HIC values of the headform predominantly did not improve when adding a neck mass.

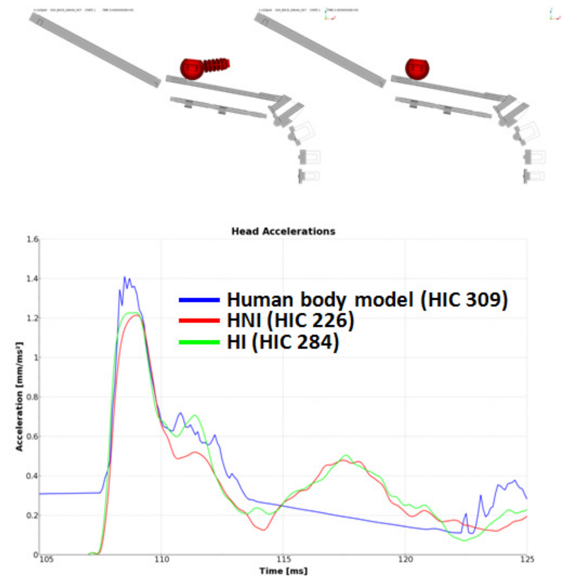

Figure 19: Comparison of 50th male human body model simulations and impactor simulations (Loop 1, SUV, 40 km/h).

The chosen vehicle front geometries with comparatively flat bonnets and without curvature can be seen as a possible reason. The HNI impactor is expected to illustrate its advantages in particular during angled impacts on rounded shapes where unrealistic impactor rotation results in values for accelerations and HIC not in line with the head loadings of a pedestrian.

In the second loop, a rigid connection between head and neck mass was established, maintaining the neck always in identical position to the head while the head being orientated according to the MADYMO simulations. Here, impact angles and speeds were taken over from the established test procedures (50° for the child head and 65° for the adult head) while maintaining an impactor velocity of 40 km/h. The results showed no improvement in terms of resultant acceleration and HIC values, as shown for the SUV Buck:

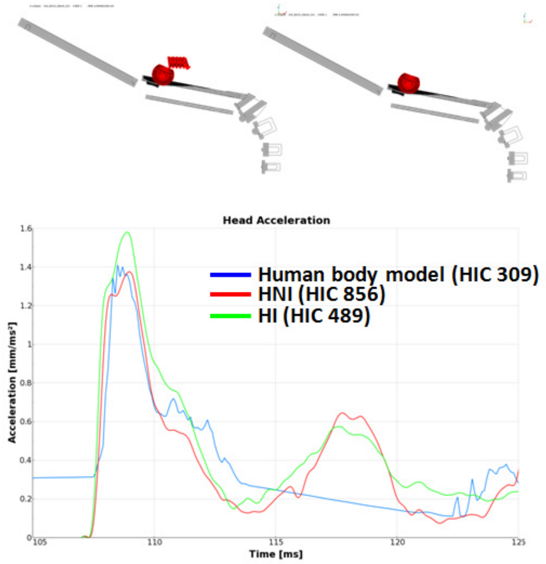

Figure 20: Comparison of 50th male human body model simulations and impactor simulations (Loop 2, SUV, 40 km/h).

On the other hand, in that case the HIC value for the HNI can be neglected. Due to the neck mass producing a high peak acceleration after the impact, a different time frame for the HIC calculation led to the assessment of the second peak. However, the second loop simulations confirmed the conclusions from the first loop. The given test conditions cannot reveal the benefits of an additional mass being added to the headform impactors. Outstanding extended simulations and tests on actual vehicles as done within APROSYS should indicate the benefit that can be expected from this modification of the head component.

Thorax injury prediction tool

First input for correlation studies to be carried out were human body model simulations with THUMS against the SAE Buck (Sedan shape) and its derivatives SUV and MPV at vehicle speeds of 20 km/h, 30 km/h, 40 km/h and 50 km/h. Subsequent simulations with TIPT used the thorax orientations and speeds of THUMS for each load case, see figure 21:

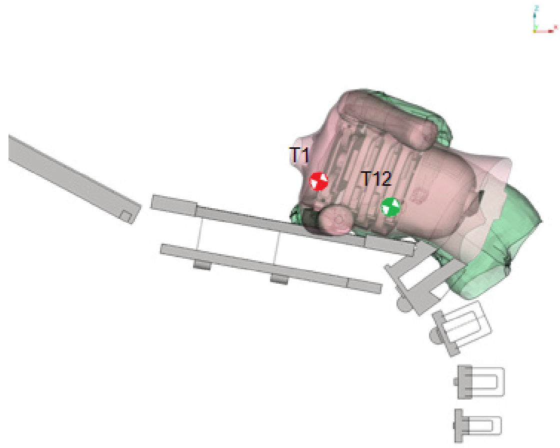

Figure 21: Comparative simulations with THUMS and TIPT.

This first loop of TIPT Baseline simulations showed the very low sensitivity of the ES-2 ribset during low speed tests, as exemplarily illustrated in figure 22 for the SUV representative. Simulations at higher impact speeds resulted in higher intrusions.

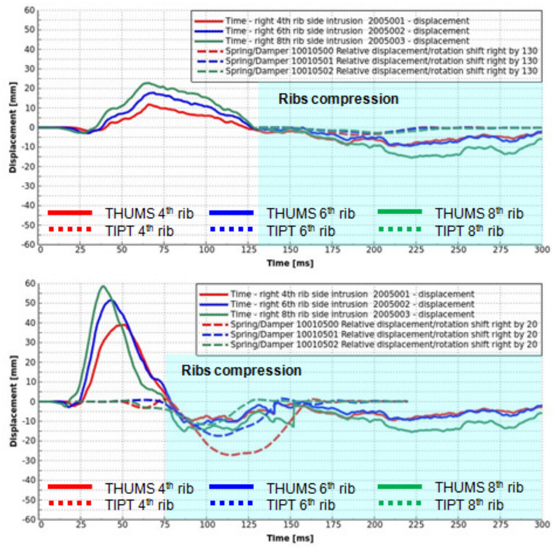

Figure 22: Comparison of THUMS rib intrusion and TIPT rib displacement during tests against the SUV representative at 20 km/h (upper) and 50 km/h (lower).

During the second loop of TIPT simulations, all load cases were repeated with additional weights applied to the TIPT. For a representation of the weights of head and neck, an additional lower neck block with a mass of 5 kg was attached to the upper end of the tool. At the lower end, a 12 kg mass was attached to the sacrum top plate to represent the weight of the pelvis, see figure 23:

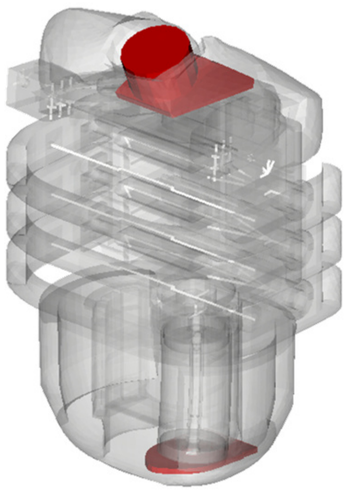

Figure 23: Modified TIPT with added weights at the upper and lower end.

Figure 24 compares the TIPT Baseline with the version with additional neck and pelvis weights and a TIPT with only the neck block attached. All variants showed some deviations in particular during impacts at higher speeds, with the highest influence of the combined attachment of head and pelvis weight. However, the sensitivity of the ES-2 thorax during low speed impacts remained low.

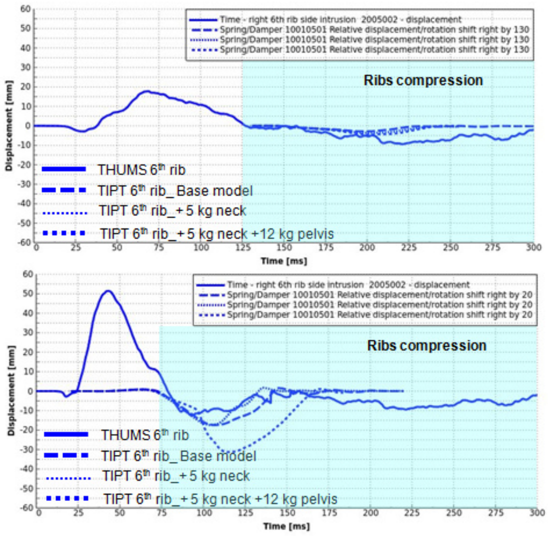

Figure 24: Comparison of THUMS 6th rib intrusion and 6th rib displacement for different versions of TIPT during tests against the SUV representative at 20 km/h (upper) and 50 km/h (lower).

FlexPLI with upper body mass

The starting point for the improvement of the upper body mass for FlexPLI and the development of a test procedure were comparative simulations with THUMS and the FlexPLI-UBM from APROSYS. These were done against a generic test rig representing four different vehicle categories (Sedan, SUV, Sports Car, Van/MPV), with three shapes per category, simulating the upper and lower end as well as an average representative. The shapes were derived from measurements of 160 actual European vehicle frontends in order to cover a broad variety of load path combinations:

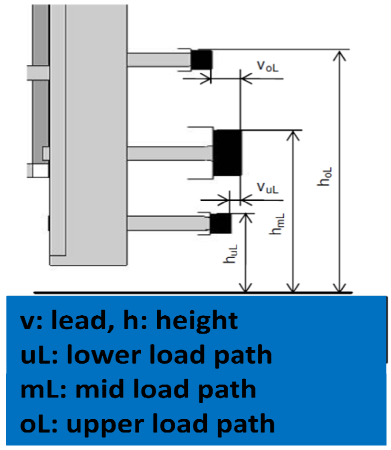

Figure 25: Test rig for comparative THUMS and FlexPLI-UBM simulations.

Foam material used for the different load paths was extruded polypropylene, with a density of 65 g/l for the upper load path, 30 g/l for the mid load path and 65 g/l for the lower load path.

As per regulatory and consumer tests 40 km/h were chosen for the impact speed. In the first loop of impactor simulations different impact angles were examined (perpendicular and oblique), the subsequent investigations focused on the perpendicular impact only. Simulations revealed sometimes unintended interactions between the rigid mass and the vehicle front leading to unrealistic results, see figure 26.

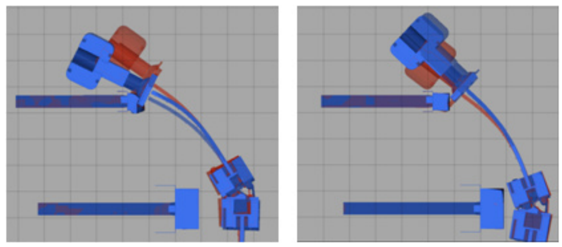

Figure 26: Interaction between FlexPLI-UBM and vehicle front at different points in time, example SUV.

To avoid this interaction, in the following simulation loop a protection kit was applied to the FlexPLI/UBM intersection (FlexPLI-UBM$_{rigid,\ PK}$). Furthermore, the influence of impact height was investigated. Finally, a second version of the UBM was introduced, connecting the mass with a flexible rubber element to the impactor at two different heights (FlexPLI-UBM$_{flexible}$). A comparison of the different FlexPLI-UBM versions is illustrated in figure 27:

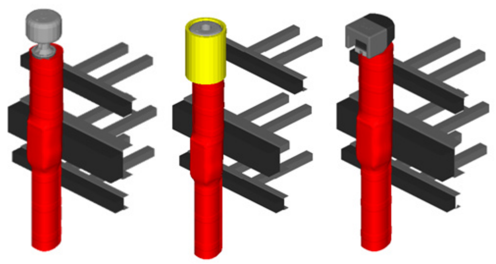

Figure 27: FlexPLI-UBM$_{rigid}$, FlexPLI-UBM$_{rigid,PK}$, FlexPLI-UBM$_{flexible}$.

As reference, all simulations were also carried out with the Baseline FlexPLI. Altogether, 192 simulations with the FlexPLI and its derivatives were performed against the generic test rig and compared to the results of simulations with THUMS. An overview of the different test setups is given in table 1:

Table 1. Overview of simulation setups using the FlexPLI and different versions of the FlexPLI-UBM.

Setup	Version	Shapes	Purpose
1	FlexPLI-UBM$_{rigid}$	12	Influence of CoG position and impact angle
2	FlexPLI-UBM$_{flexible}$	4	Influence of flexible connection Influence of rubber material variation Influence of rubber height variation
3	FlexPLI-UBM$_{rigid, PK}$	12	Effect of protection kit Influence of CoG position
4	FlexPLI-UBM$_{rigid, PK}$	12	Influence of impact height
5	FlexPLI	12	Reference
6	THUMS	12	Reference

Influence of CoG The rigid version of the FlexPLI-UBM was tested in four different locations regarding its center of gravity: center lower, center upper, offset lower, offset upper. Figure 28 gives an example of the influence of the CoG location, where a variation of its height is of a higher significance than the variation of the offset, latter one not influencing the shape of time history curves.

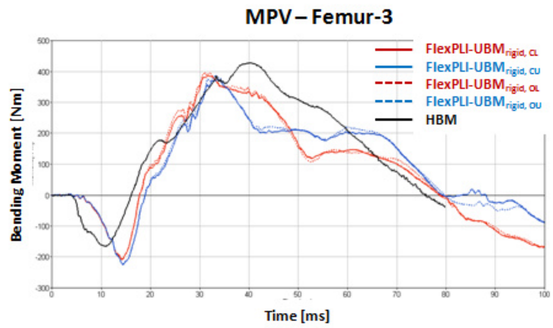

Figure 28: Influence of CoG location of the rigid upper body mass, example femur-3 vs. MPV.

Influence of flexible mass A second version of the upper body mass, equipped with a flexible rubber made out of three different materials (WorldSID 50th lumbar spine rubber, Q10 neck rubber, HIII 50th lumbar spine rubber) was tested and the results compared to those obtained with the rigid UBM. As demonstrated in figure 29 for the baseline MPV representative, in most cases no elementary changes in time history curves were achieved by using the upper body mass with flexible element; its application as well as the use of the rigid mass contributed to a significantly enhanced time history curve. A next step, where the attachment of the flexible mass was shortened, did not result in further improvement of the quality of correlation.

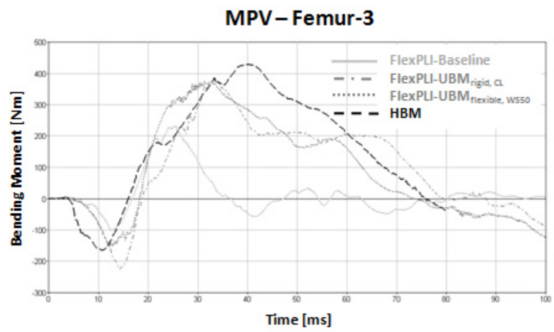

Figure 29: Comparison of FlexPLI Baseline, FlexPLI-UBM with rigid connection (center lower position) and FlexPLI-UBM with flexible connection (WS50th rubber) to human body model simulation, example femur-3 vs. MPV.

Influence of protection kit As already described, different vehicle designs may lead to an unintended interaction between the vehicle front and the connection between rigid upper body mass and FlexPLI, see figure 26. Therefore, to avoid this interaction, a protection kit was designed. As can be seen in figure 30, the protection kit contributes to avoiding this interaction and unrealistic peak results.

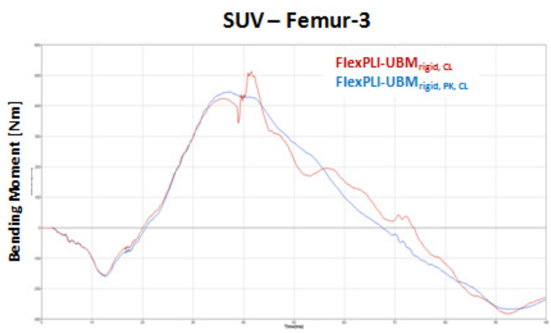

Figure 30: Comparison of FlexPLI-UBM with rigid connection (center lower position) and FlexPLI-UBM with rigid connection and protection kit, example femur-3 vs. MPV.

It was therefore decided to carry on the study using the protection kit for the rigid upper body mass.

<u>Influence of impact height</u> An earlier study from Konosu et al. (2007) already showed the influence of impact height on the test results. Using the FlexPLI Baseline, it was found that an impact height for the FlexPLI lower edge of 75 mm above ground level would improve the degree of correlation with maximum output levels between FlexPLI and a human body model. Therefore, it was subsequently decided to use 75 mm impact height as standard setup when testing with the FlexPLI.

To further investigate within this study a potential improvement of the quality of correlation between the FlexPLI-UBM and THUMS, the FlexPLI-UBM impact height above ground level was varied between 0 mm, 25 mm, 50 mm and 75 mm. It was found that for those areas close to the knee (femur-1, tibia-1 and tibia-2) an impact height increased by 25 mm could slightly contribute to the correlation of maximum output values, but however, along with an overall declination of biofidelity in the femur area. Therefore it was decided to keep the impact height with the lower end of the impactor at ground level.

Figure 31 illustrates the kinematics of the FlexPLI-UBM (rigid connection) with the FlexPLI Baseline and the lower extremities of THUMS during impact against the second SUV representative.

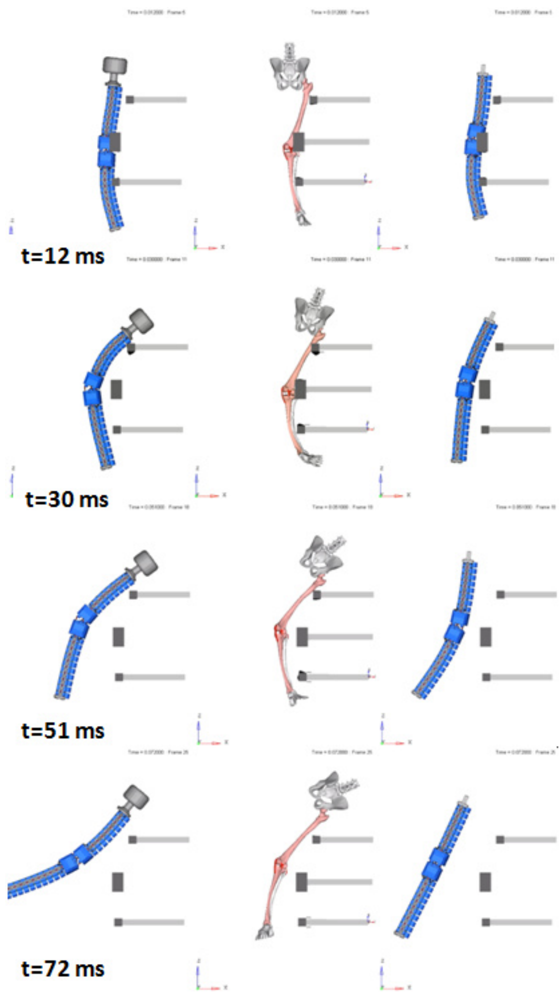

Figure 31: Impact kinematics of FlexPLI-UBM$_{CL}$, THUMS and FlexPLI Baseline during impact against SUV-1.

The very good correlation between the FlexPLI-UBM$_{CL}$ and the lower extremities of THUMS during the impact phase against the SUV-1 are confirmed by the corresponding time history curves, see figure 32. While the FlexPLI Baseline is starting its rebound at a point in time significantly before the zero crossing of the femur segments, the duration of impact of the impactor with applied UBM is much more humanlike, both ending the impact phase of the femur area at approximately 70 ms after t0. The shape of time history curve does not correlate that well for the tibia, however the timing of the impact is more comparable between FlexPLI-UBM and THUMS. For MCL, timing and extent of the plots of FlexPLI-UBM are again close to THUMS.

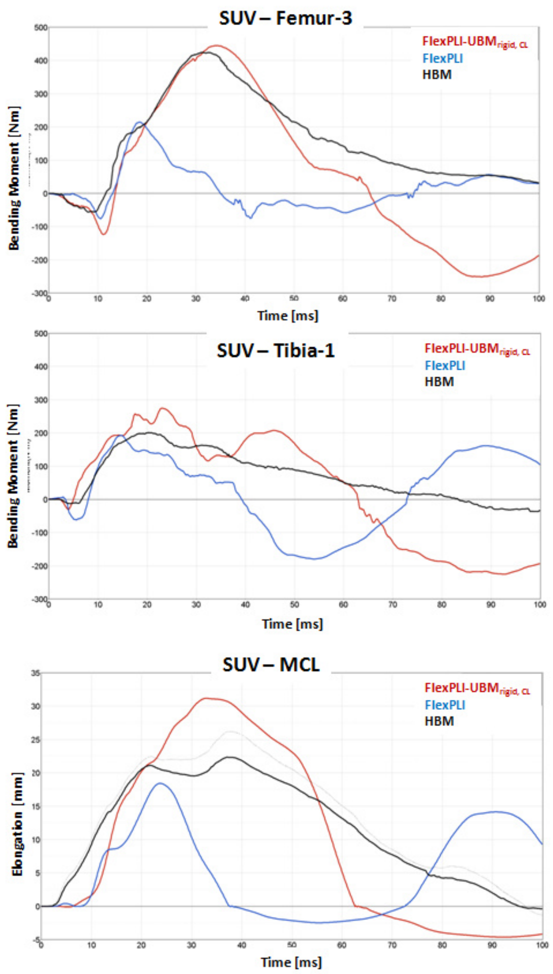

Figure 32: Time history curves of FlexPLI-UBM$_{CL}$, THUMS and FlexPLI Baseline during impact against SUV-1.

Altogether, during simulations with the FlexPLI Baseline and the FlexPLI with different versions of an upper body mass it could be seen that in most cases a mass representing the torso significantly contributes to an improved kinematics and improved time history curves, where the highest influence was observed due to application of the mass itself. A variation of attachment method (rigid or flexible), location of the center of gravity or the type of rubber material for the flexible element showed having a small but not significant influence and could therefore be reconsidered for final revision of the impactor. For the rigid connection, a protection kit should be used to avoid unintended interaction. The impact height should remain at ground level, since - different to the FlexPLI Baseline - the pedestrian torso is now represented by the applied mass.

CORRELATION STUDIES

Thorax injury prediction tool

First evaluation of the THUMS and TIPT time history curves of rib intrusion and rib displacement already revealed the low sensitivity of the ES-2 thorax under low impact speeds for all three ribs. This observation is underlined when looking at the rib wise maximum TIPT displacement vs. the maximum THUMS rib intrusion. Best correlation over all impact speeds and vehicle shapes was found for the 4th rib. On the other hand, when focusing on impact speeds of 40 km/h and 50 km/h only, but including the maximum rib displacement over all ribs as injury assessment criterion, the coefficient of determination could be improved accordingly:

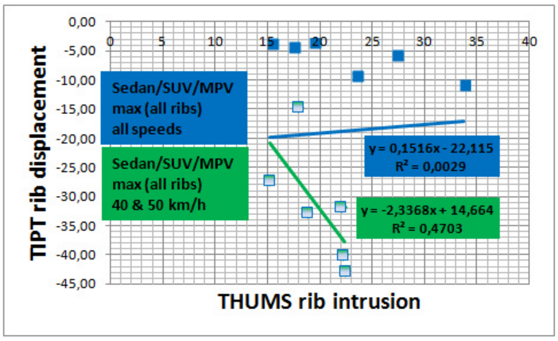

Figure 33: Correlation of THUMS maximum rib intrusion vs. TIPT maximum rib displacement at higher impact speeds.

A modification of the TIPT by adding a weight to the neck or to the neck and the pelvis likewise did not improve the overall results in terms of correlations, but could significantly improve correlations for the 4th rib (TIPT version with additional neck and pelvis load), as depicted in figure 34.

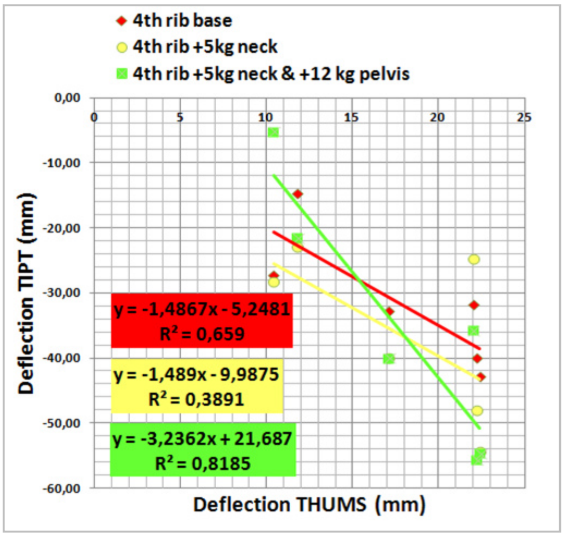

Figure 34: Correlation of THUMS 4th rib intrusion vs. TIPT 4th rib displacement at higher impact speeds.

One reason for the comparatively unsatisfactory correlation of maximum output values is expected to be the impact condition of TIPT. At initial position TIPT is recommended to be kept in a yz plane parallel to the xz plane of the impacted vehicle, being the direction in which rib displacement is measured with the ES-2 dummy. Future simulations will therefore focus on the respective alignment of TIPT when being fired.

FlexPLI with upper body mass

Extensive studies of FlexPLI correlations with THUMS lower extremities showed best results for the FlexPLI with rigid upper body mass and protection kit, at center lower position of the UBM center of gravity, and at an impact height at ground level. The degree of correlation over all vehicle shapes for the femur-1 area is given in figure 35:

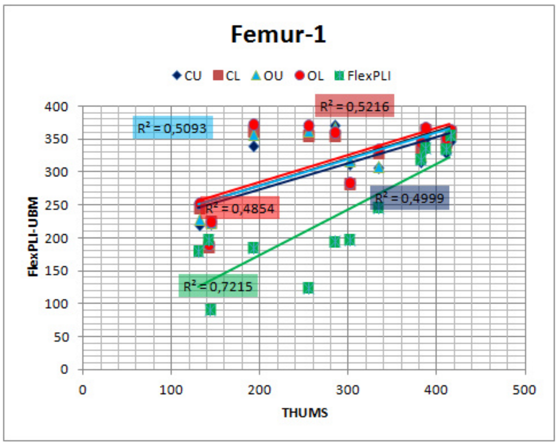

Figure 35: Correlation of FlexPLI, FlexPLI-UBM$_{rigid,\ PK}$ with THUMS lower extremities at segment femur-1, all vehicle shapes.

While the influence of CoG location on the correlation is very low, the best correlation in that area is obviously achieved by the FlexPLI Baseline, which is considered not being biofidelic in that area, as also proved by time history curves. Looking at the peak values it seems to clarify this phenomenon: while the FlexPLI Baseline with basically lower results than the FlexPLI-UBM can show a broad range of output values, the FlexPLI-UBM is in many cases protected by the bone overload wiring, not allowing the impactor to go into more bending. Thus, as in the example from figure 35, the range of bending moment for THUMS is about 300 Nm while the values of the FlexPLI-UBM move between 190 and 370 Nm only. It can be concluded that the FlexPLI-UBM which per definition is starting at higher values than the FlexPLI having a much lower sensitivity in the femur area due to its overload protection devices.

For the tibia area, this trend cannot be confirmed. While bending moments of THUMS have a range of approx. 80 Nm in the case of tibia-2, the range for FlexPLI Baseline as well as FlexPLI-UBM contains 160 Nm:

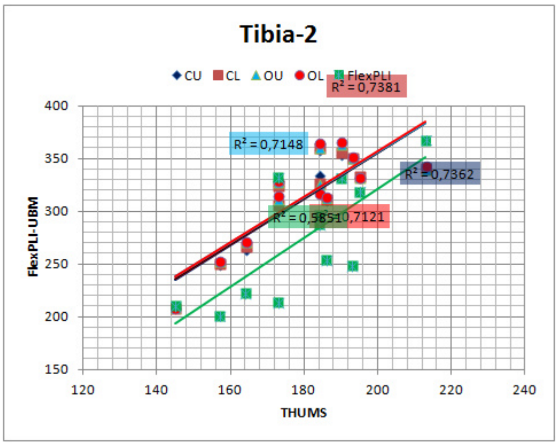

Figure 36: Correlation of FlexPLI, FlexPLI-UBM$_{rigid,\ PK}$ with THUMS lower extremities at segment tibia-2, all vehicle shapes.

It can be concluded that the FlexPLI-UBM sensitivity in the tibia area is in the range of the sensitivity of FlexPLI Baseline.

DISCUSSION

Recent vulnerable road user accident data reveals the need for revision of current pedestrian test tools and test as well as assessment procedures. Besides the head and lower extremities, the thorax is now in the focus of research for both, pedestrians as well as cyclists regarding all age groups. SENIORS is examining the revision and further development of surrogates representing the head and the lower extremities of vulnerable road users. Besides, the development of an injury prediction tool for the thorax is initiated. First simulation results indicate the head neck impactor whose development was started during the FP6 project APROSYS possibly not being the appropriate mean for improving impactor kinematics for a broader variety of vehicles. The adaptation of the impactor taking into account different front shapes remains an item for future investigations. Results from simulations with the TIPT indicate the applicability in particular during impacts at higher speeds. However, the sensitivity of the ES-2 thorax at lower impact speeds does not lead to the conclusion of this new tool being convenient for low speed conditions. Since test speed is expected to be in line with remaining regulatory VRU testing, the TIPT impact speed is aimed to reflect a vehicle speed of 40 km/h. The FlexPLI with applied upper body mass shows significant improvements regarding kinematics, shape of time history curves and loadings in comparison to the FlexPLI Baseline. On the other hand, sensitivity of the femur area needs to be improved.

CONCLUSIONS

Taking into consideration recent in-depth accident data of pedestrians and cyclists of all age groups during collisions with passenger cars, new and improved test tools and procedures are being developed within the SENIORS project. Simulations with the head neck impactor already showed at an early stage of the programme that the development derived from the APROSYS project is not yet ready for implementation within consumer or regulatory testing. Further research is needed in that field, demonstrating the benefit of an additional neck mass limiting the impactor rotation during the impact within a more realistic range. On the other hand, first promising simulation results with TIPT have indicated the ES-2 torso being applicable for assessing rib injuries to vulnerable road users at speeds representing consumer or regulatory vehicle speeds of 40 km/h and 35 km/h respectively. Additional simulations will be carried out, further investigating specific items such as the TIPT rotation around its vertical axis prior to impact. Prototyping of a first impactor is planned during a subsequent research project. The FlexPLI-UBM shows a much better correlation with human body model simulations regarding kinematics, shape of the traces and loadings as the FlexPLI Baseline impactor. During further research, the sensitivity of the femur is needed to be improved, before prototyping of the impactor starts and the achieved results will be validated under application of a new test and assessment procedure.

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