Latest FE Model Development of THOR-50M Crash Test Dummy

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Abstract

THOR-50M LS-DYNA® Finite Element (FE) dummy model, developed by Humanetics (Humanetics Innovative Solutions, Inc.), has been widely used in occupant safety by OEMs and suppliers and has proved to be a mature model since its first release in early 2014. In the next two years, major development work had been completed, including material characterization, component validations, sled test validations and robustness verifications.

The latest release of version 1.5 FE model focused on improving the thorax. New tests were carried out on single rib, as well as on thorax and on whole dummy level for FE model improvement.

Version 1.5 also reflected the recent update of the Anthropomorphic Test Device (ATD), commonly known as crash test dummies, includes build level A and B (SBL-A, SBL-B) update for US NCAP (New Car Assessment Program) version, and SBL-A update for Euro NCAP version. The two versions differ in physical part design, certification performance requirements and more, resulting in two different FE models.

Introduction

As with all FE models, crash test dummy models consist three critical aspects: accurate geometry, material modeling and structural connectivity. As part of the largest and most established manufacturer of physical ATDs, the Humanetics CAE group has access to the most up-to-date hardware which ensures that the delivered FE models incorporate the latest geometry and materials. Material characterization and modeling in Humanetics FE dummies has become increasingly important over time as more accurate model responses are required. The use of advanced material models and extensive material testing has allowed for more representative non-linear and rate-dependent responses in a number of key components [1].

To validate each dummy model, Humanetics has developed stringent processes to carry out an extensive amount of physical tests, ranging from component to sub-assembly and full dummy levels, covering a wide variety of loading conditions at various levels of complexity to ensure the model's predictive capabilities are as high as possible. Some of these tests are required to certify the physical dummy while most are non-certification tests carried out specifically for dummy model validation purposes. Along with rigorous quality assurance checks and robustness verifications, all FE dummy models can sustain severe loading without causing pre-mature simulation termination.

The presented work summaries the work prior to V1.5 development, then highlights the major work completed for V1.5 model, with a focus on chest performance improvement.

THOR-50M FE Model Development Prior to Version 1.5

Tremendous amount of work had been done to develop THOR-50M FE model since 2013. More than forty deformable materials were tested, their material characteristics were extracted and verified in coupon simulations, then further fine-tuned in component test validations. Key components that were tested and validated include rib, neck, thoracic spine, lumbar spine, abdomen, knee slider, pelvis, ankle and foot. All different level validations, from component to sub-assembly and whole dummy, are carried out at different energy levels (initial velocities) to evaluate the model performance in rate sensitive dynamic loading environment.

Geometry verification (Figure 1) was done by using laser scan of the assembled dummy, as dummy parts may take a slightly different shape than when all are assembled, especially in the thorax. With the scan data of physical dummy, faithful representation of geometry was achieved in the FE model.

Three key components in the dummy received special attention during development - neck, lumbar spine and thoracic spine. For example neck can undergo considerable torsion when the dummy is loaded in the vehicle tests constrained by seatbelt and airbag. Earlier versions of neck model was quite good at predicting injury in bending mode, but not so for torsion. To better predict BrIC injury, pure torsion tests (Figure 2) were designed for neck, and later on mini-sled tests were executed, which have combined deformation modes of both bending and torsion, were added to complement flexion, extension and lateral bending tests. Similar tests were done for lumbar spine and thoracic spine as well, and extremely good correlation was achieved for those 3 components in about 12 different tests for each component.

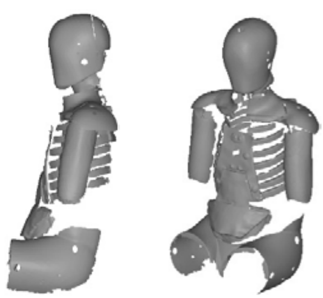

Figure 1: Laser scan for geometry verification

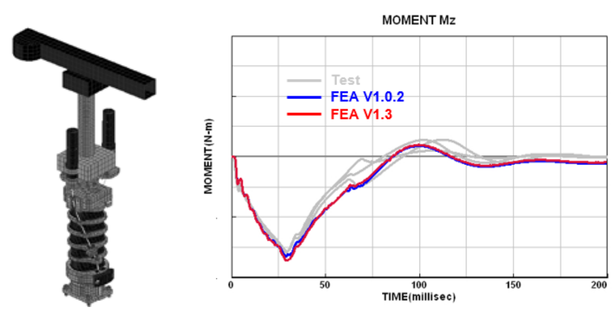

Figure 2: Neck pure torsion validation

Validation of dummy model in sled test environment is essential for a good quality model, simple sled tests with rigid seat and seatbelt in oblique loading conditions (Figure 3) were used to validate THOR-50M FE model currently, before more advanced sled test data become available.

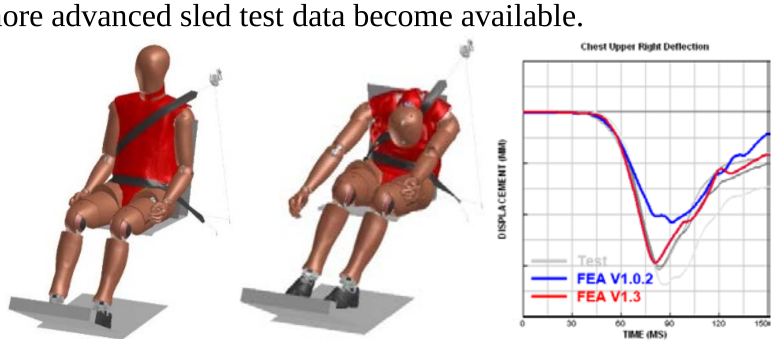

Figure 3: Sled validation

Multiple robustness cases were developed to evaluate FE dummy model stability. In those cases, rigid seats were used with seatbelt constraining the dummy model, with scaled up sled pulse. Those cases were done for straight and oblique loading, for both driver and passenger positions to ensure that FE dummy model can run to the end of simulation without abnormal termination or contact failure. As result of this effort, most users have very good experience using THOR-50M FE model in their analyses. Figure 4 shows some of those cases.

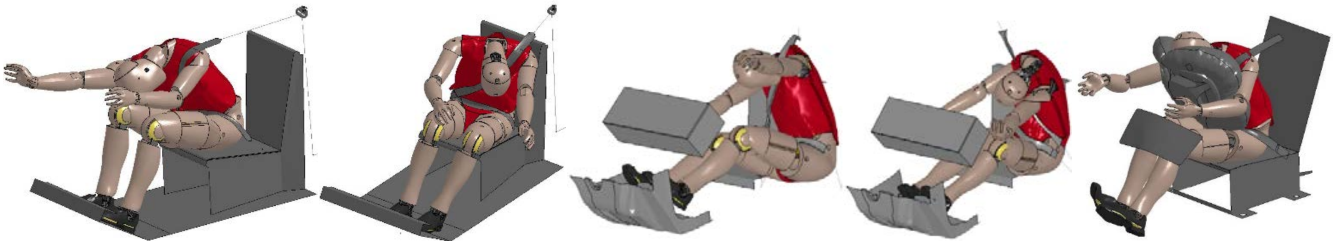

Figure 4: Robustness verifications

Because of the enormous investment in development mentioned above, V1.4 (Figure 5) was already a mature FE model and was widely used for occupant safety evaluation with this new test dummy for NCAP.

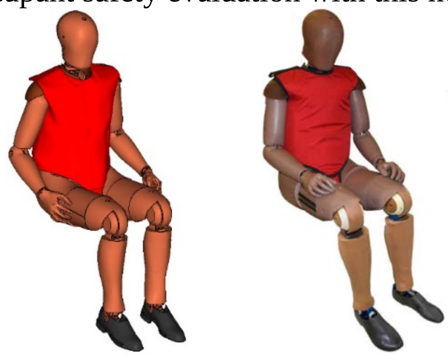

Figure 5: THOR-50M LS-DYNA model (left) and physical ATD (right)

New Development in Version 1.5 FE Model

National Highway Traffic Safety Administration (NHTSA) certification guideline (draft) was published in August 2016 [5], in which included changes to test speeds and corridors, dummy positioning, also the shape of the probe for abdomen certification. Since then the manufacturer of the ATD (Humanetics Innovative Solutions, Inc.) has conducted many certification tests on existing and new production ATDs, and the certification corridors had been discussed with NHTSA and adjusted, resulting in service build level A and B (SBL-A, SBL-B) [2, 3, 4] along with small design changes to parts.

Updates in SBL-A that affect FE dummy model include longer neck front cable, more relaxed lower abdomen bag, doubled sided tape used to attach lower abdomen front and rear foam pads together, more rounded corners for A.S.I.S load cells, added straps around sternum bonding assembly to prevent foam from tearing, as shown in Figure 6.

Figure 6: SBL-A updates

Most updates in SBL-B don't affect FE model (such as improved design of IR TRACC mounts), what affects FE model is the adjustment in performance requirements of certification tests (corridors). V1.5 model was certified following NHTSA's guideline and achieved satisfactory result in meeting the corridors.

Neck torsion certification was a new test proposed in NHTSA's certification guideline, V1.5 neck model performs very well in torsion certification (Figure 7) and can be used to study BrIC with more confidence.

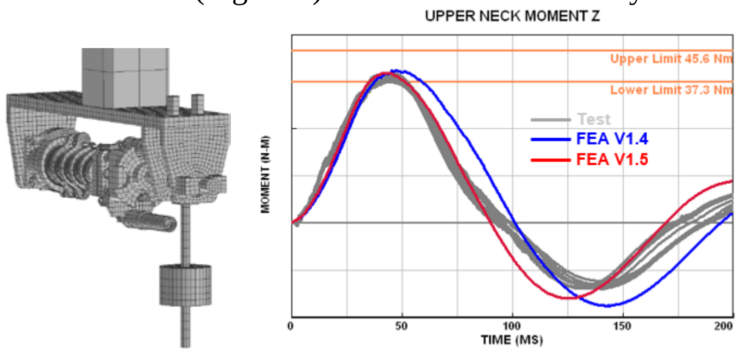

Figure 7: Neck torsion certification validation

Besides keeping up the updates in physical ATD, a number of new component tests were carried out to further improve V1.5 FE model. Following new tests were added to the existing extensive validation suite:

Single rib drop tower tests (Figure 8, 9) in three orientations, each was carried out at two speeds to achieve low and high rib deflections. The three orientations are straight, angled and oblique, designed to simulate different loading conditions that physical ATD undergoes in vehicle tests.

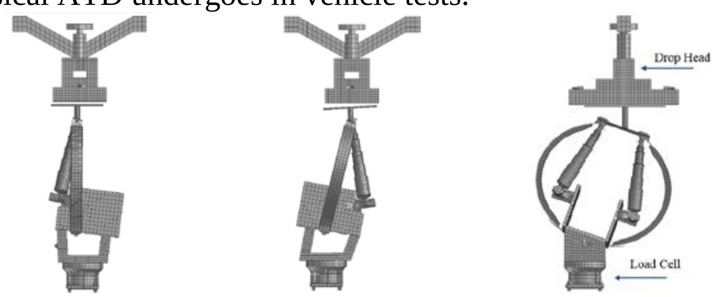

Figure 8: Single rib tests – Straight, Angled and Oblique

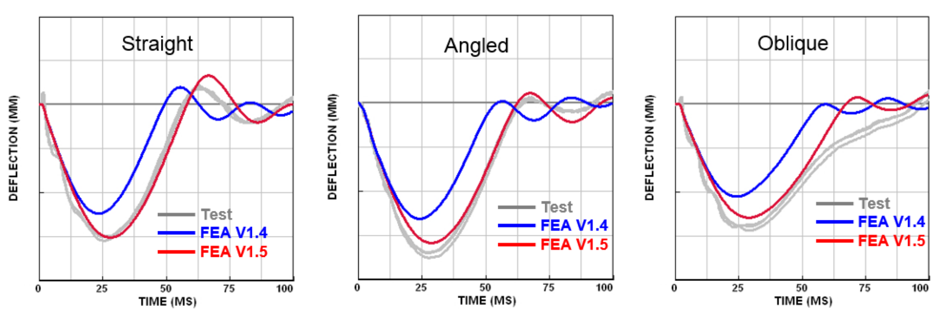

Figure 9: Single rib test validations - Straight, Angled and Oblique

Bib 3-point bending tests were realized to validate this critical component which contributes directly to dummy chest deflection. It turned out the material implemented FE model prior to V1.5 already represents the physical part quite faithfully (Figure 10).

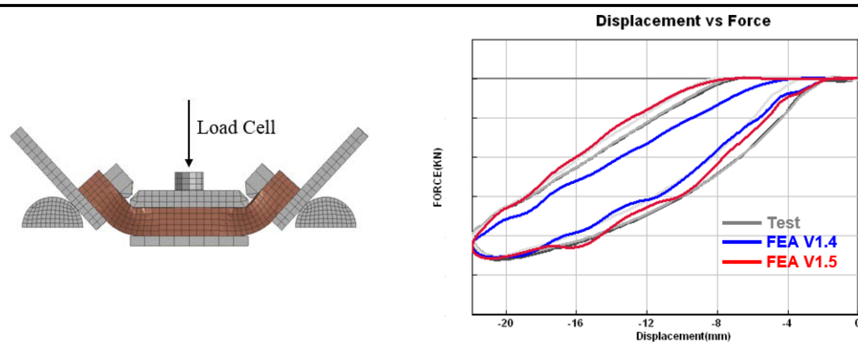

Figure 10: Bib 3-point bending validation

Built on the foundation of well validated component models, the materials of ribs were further tested in sub-assembly tests – thorax pendulum tests (Figure 11), in which thorax was fixed at the back, hit by a probe at different speeds from different angles at different locations, 6 test configuration in total, were used in V1.5 model validation (Figure 12) to further enhance the model capability in predicting chest deflection.

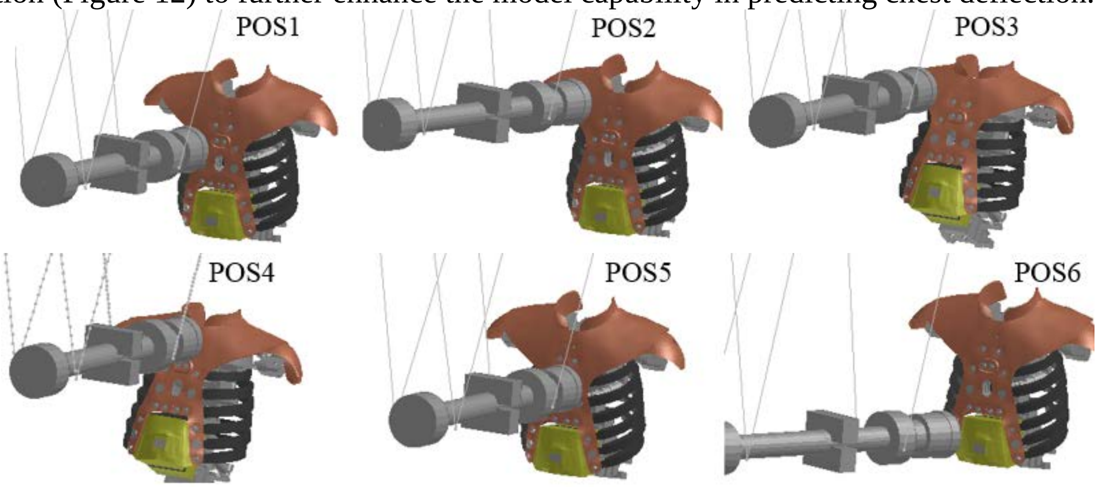

Figure 11: Thorax pendulum tests

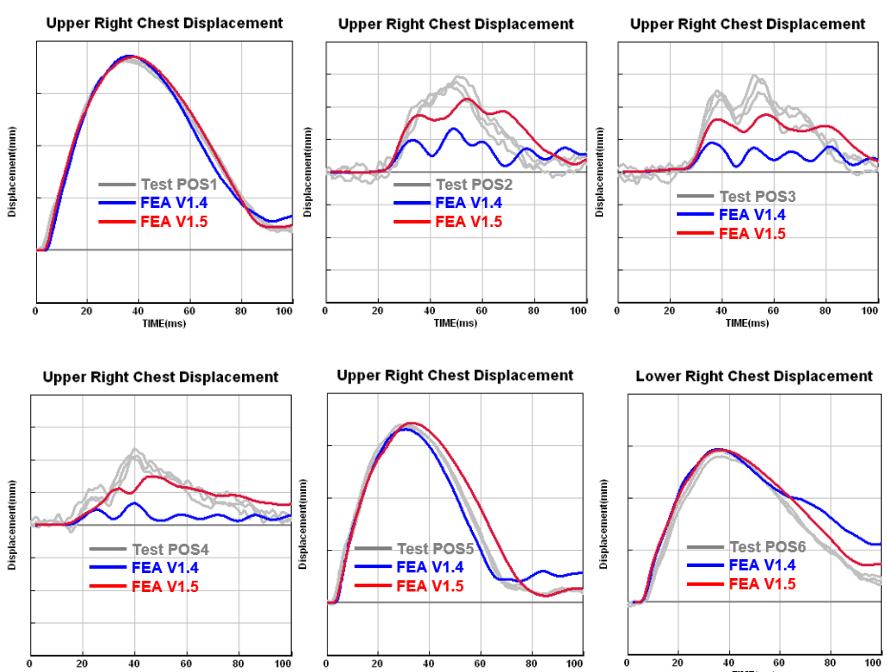

Figure 12: Thorax pendulum validations

V1.5 FE model was ultimately scrutinized in the whole dummy tests, including all certification tests (NHTSA guideline August 2016), and non-certification tests (Figure 13, 14) which were newly introduced into V1.5 validation suite. As a result of this effort, further improvement was achieved.

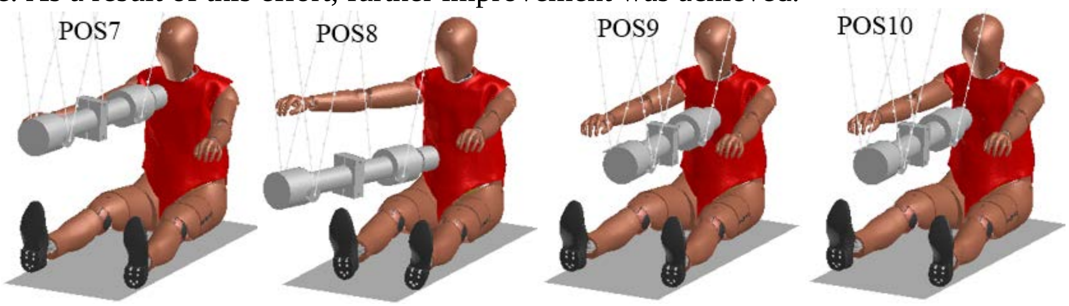

Figure 13: Whole dummy pendulum tests (non-certification)

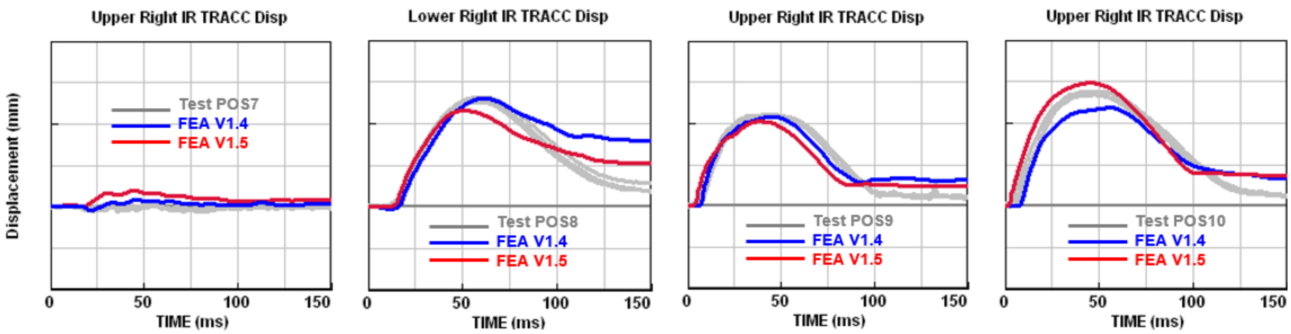

Figure 14: Whole dummy pendulum validations (non-certification)

FE model was validated in sled test prior to V1.5, passenger side test (Figure 15) was added to the validation suite of V1.5.

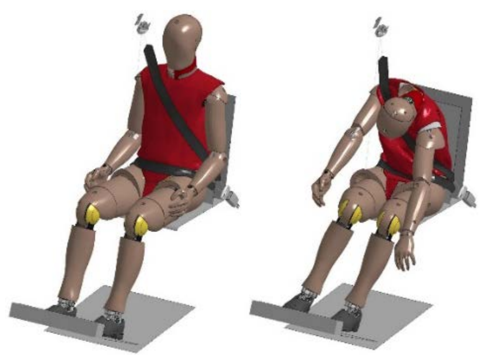

Figure 15: Sled test validation - passenger

Euro NCAP V1.5 Model

Euro NCAP version of THOR-50M ATD is equipped with Hybrid III 50th knee sliders and lower legs (Figure 16), a different design of spine pitch mechanism, and complies with SBL-A design [3] currently. As a result, attention was paid to ensure that Euro NCAP FE model V1.5 meet SBL-A performance requirements in certification tests (Figure 17). FE model of knee slider and lower leg was borrowed from Harmonized H3-50 FE model and they were validated extensively in HH350 model development [5].

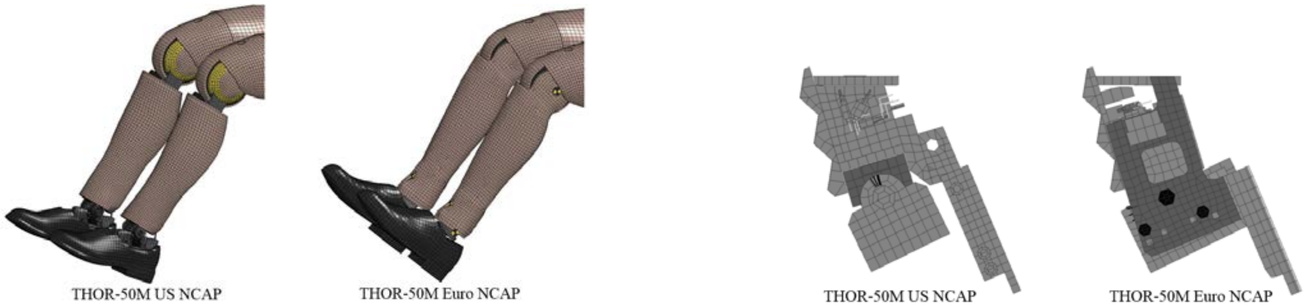

Figure 16: US NCAP vs Euro NCAP

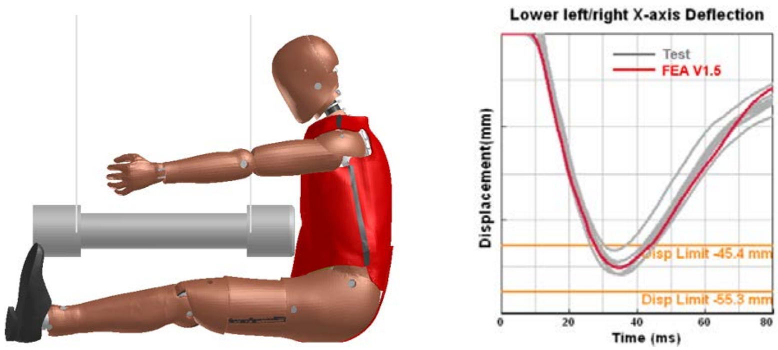

Figure 17: Euro NCAP model certification (lower thorax)

Statistics of THOR-50M V1.5 LS-DYNA FE Model - consists of 445K nodes and 476K deformable elements. An initial time-step of 0.7 micro-second was achieved for the dummy model. The V1.5 FE model has been tested using the LS-DYNA solver version R7.1.2.

Conclusions

The following conclusions can be drawn from the presented work:

- Very detailed THOR-50M V1.5 dummy models was developed using the LS-DYNA FE solver, its performance was on a higher level, compared to previous versions.
- Hardware updates in SBL-A and SBL-B were implemented in V1.5 model of US NCAP and Euro NCAP configurations.
- Main focus of V1.5 development was on thorax assembly.
- Both US NCAP and Euro NCAP models demonstrate extremely promising predictive capabilities.

References

[1] Newly Developed LS-DYNA Models for THOR-M and Harmonized HIII 50th Crash Test Dummies, Chirag S. Shah, et al, Humanetics Innovative Solutions, Inc., Farmington Hills, MI (USA), 13th International LS-DYNA Users Conference.
[2] THOR-50M U.S. NCAP SBL-A Update, January 2017, Humanetics Innovative Solutions, Inc., Farmington Hills, MI (USA)
[3] THOR-50M Euro NCAP SBL-A Update, January 2017, Humanetics Innovative Solutions, Inc., Farmington Hills, MI (USA)
[4] THOR-50M Standard SBL-B Update, January 2018, Humanetics Innovative Solutions, Inc., Farmington Hills, MI (USA)
[5] THOR 50th Percentile Male (THOR-50M) Qualification Procedures Manual, Draft August 2016, National Highway Traffic Safety Administration (NHTSA)