# A Simulation-based Approach for Improved Thorax Injury Risk Function for the THOR ATD

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## I. INTRODUCTION

Thorax injury is one of main causes of serious injury in frontal collisions, especially for elderly car occupants [1]. The anthropometric test device (ATD) THOR-M provides chest deflection measurements at multiple locations, to assess the risk of thorax injury. For this purpose, risk functions are needed that relate the potential criteria based on multipoint chest deflection measurement to injury risk. Different thorax injury criteria and risk functions for THOR have been proposed [2-3]. The criteria and functions are based on the traditional approach to developing injury risk functions using matched ATD and PMHS tests by relating the injury (number of fractures) to injury criteria. Regarding these studies, some limitations have been identified, in particular concerning the loading conditions of the data used (mainly 3-point-belt loading, high loading severity [2], out-of-date ATD versions [3]).

To extend the data set and overcome these limitations, a new approach for improved thorax injury criteria was applied within the EC-funded project SENIORS. The new approach is based on matched frontal impact sled computer simulations with a model representing the latest THOR-M ATD version, and matching simulations with a human body model (HBM) representing an elderly car occupant.

## II. METHODS

### *Definition of test and simulation plan*

To compare output from the THOR dummy and the HBM, a test and simulation matrix were defined to cover a broad range of matching loading conditions using load cases from the literature, e.g. tests based on the gold standard test-rig [4]. For these load cases, ATD and matching PMHS test data were available for validation of the ATD and HBM simulations. Furthermore, the experimental test set-up and CAE model were available. Also within SENIORS, a new simplified generic but representative sled set-up was developed [5]. This generic test set-up was tuned by HBM simulations and tests and simulations with THOR to be much more representative of modern vehicle occupant restraints compared to previously simplified sled test set-ups reported in literature.

Based on the load cases from literature, an extended simulation matrix was defined by variation of test parameters and conditions. The parameters comprised: impact severity with acceleration pulses between 25 km/h and 56 km/h; variation of restraint systems, including loading condition with and without airbag, with and without pretensioner; variation of 3-point-belt load limiter level (no load limiter, limiter levels between and 2.7 kN and 6 kN); and loading by alternative restraints, such as 4-point belts. Initial findings in this paper are based on a preliminary data set of 40 load cases with matching HBM and a THOR-M ATD simulation results.

### *Occupant models and processing of output data*

The HBM used for this study is a modified version of THUMS-TUC [6]. The modification consisted of material and geometry changes to the rib cage to represent an 64yo+ car occupant [7]. A rib strain-based probabilistic fracture risk prediction method proposed by Forman *et al*. [8] was applied with THUMS-TUC to predict for each load case an injury probability of sustaining equal or more than one, two or three fractured ribs.

Matching simulations with THOR-M (Humanetics LS-Dyna Version 1.3.2) were conducted. Care was taken to position the ATD as similarly as possible, matching to the HBM in the sled environment by matching the H-point and aligning the front part of the chest. For each THOR simulation, two candidate injury criteria were calculated based on the four-point resultant deflection predictions: the maximum of the four resultant peak deflections ($R_{max}$) and the PCA Score, a combined metric that was generated from a principal component analysis [2]. Based on the rib fracture predictions from HBM simulations and injury criteria from ATD simulations, logistic regression models were used to create injury risk functions.

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## III. INITIAL FINDINGS

Comparison of the ATD and HBM output in terms of predicted injury and dummy deflections to the experimental results in the literature showed reasonable agreement to provide sufficient confidence in this simulation-based approach. However, it also indicated the need for further improvement of the occupant simulation models and the rib fracture prediction method.

The 40 matching simulations with THOR and HBM in various loading conditions resulted in $R_{max}$ deflections ranging between 20 mm and 56 mm and PCA Scores between 2.51 and 7.20. The results for the HBM predicted risk for equal or more than one, two or three fractured ribs vs $R_{max}$ and the PCA Score, respectively, can be seen in Fig. 1, together with the risk curves. All p-values are less than 0.05, which indicates statistical significance.

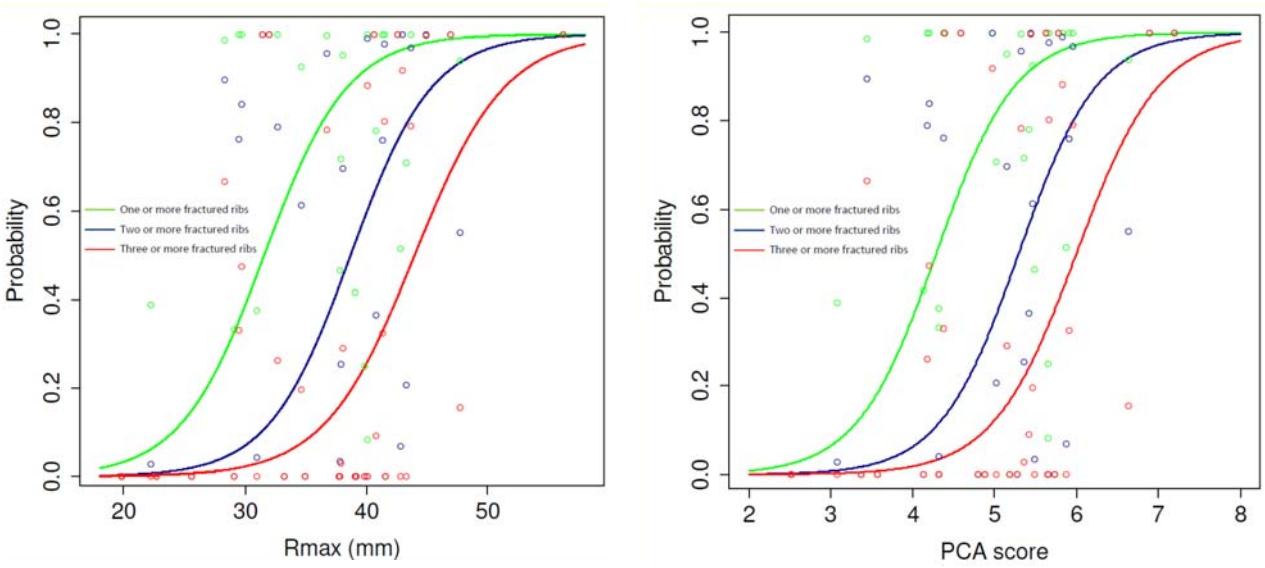


Fig. 1. Probabilistic risk for equal or more than one, two or three fractured ribs vs $R_{max}$ and PCA score.

## IV. DISCUSSION

The main motivation of this simulation-based approach was achieved, i.e. to address one major limitation of current experimental-based testing data sets. The results represent a broader range of chest loading patterns in terms of peak and differential deflection indicated by a wide range of $R_{max}$ and PCA values. The initial results regarding new risk curves look very promising.

Limitations of this approach can be clearly seen in the need for an improvement of the validity of the applied simulation models and the rib fracture prediction approach. Therefore, SENIORS recommends to repeat the defined simulation plan of extended loading conditions with an improved version of the ATD model that has recently become available and also improved HBM versions. Matching simulations with a different HBM are also recommended to confirm HBM predicted injuries.

In a next step, an HBM-based deterministic rib fracture assessment by defining a failure strain threshold will be applied to provide AIS3+ risk curves. Furthermore, in this study the PCA coefficients proposed by Poplin [2] were used. It is intended to re-conduct the principal component analysis with the new extended data set from SENIORS to potentially improve the calculation of the PCA score metric itself.

## V. ACKNOWLEDGEMENTS

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