Exploratory Injury Assessment of Thoracic Spine Loading in Deep Reclined Seating Using the SAFER HBM

Krystoffer Mroz, Ema Jokubaityte, Manuel Valdano, Francisco Jose Lopez-Valdes

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Background

- New vehicle interiors and automated driving concepts enable non-conventional seating configurations
- Occupants may move into various reclined postures when adjusting the seat cushion and seat back

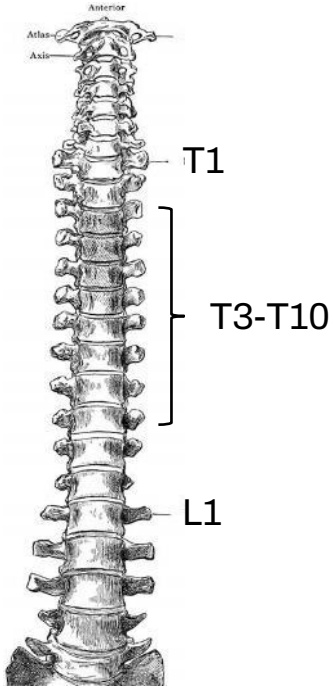
Illustrations of enhanced flexibility

ENOP –
Enable New Occupant Seating Positions

- 12 PMHS in SP1-SP5, targeting mid-sized males
  - Semi-rigid seat: No restraining of the feet
  - Prototype restraint system: Triple pretensioning and load-limiting (shoulder 4, lap 5 and buckle 7 kN), with a crash locking tongue

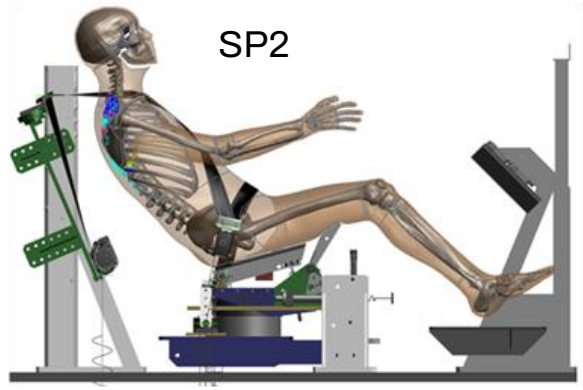
- Increased mid-thoracic vertebral body fractures for increased recline:
  - SP1 and SP2: No thoracic fx between T3-T10
  - SP4: 2/3 PMHS sustained one or more fx between T3-T9
  - SP5: 1/3 PMHS sustained three fx between T6-T10

- Experimental results from ENOP are planned to be published during 2026



SP1	SP2	SP4	SP5
			
Seat pan : 15° Back : 22°	Seat pan : 15° Back : 45°	Seat pan : 25° Back : 60°	Seat pan : 40° Back : 60°

Frontal 50km/h, 35g | Frontal 40km/h, 28g



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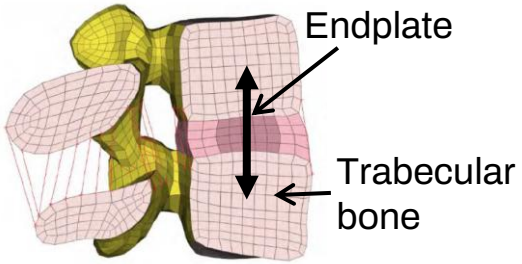
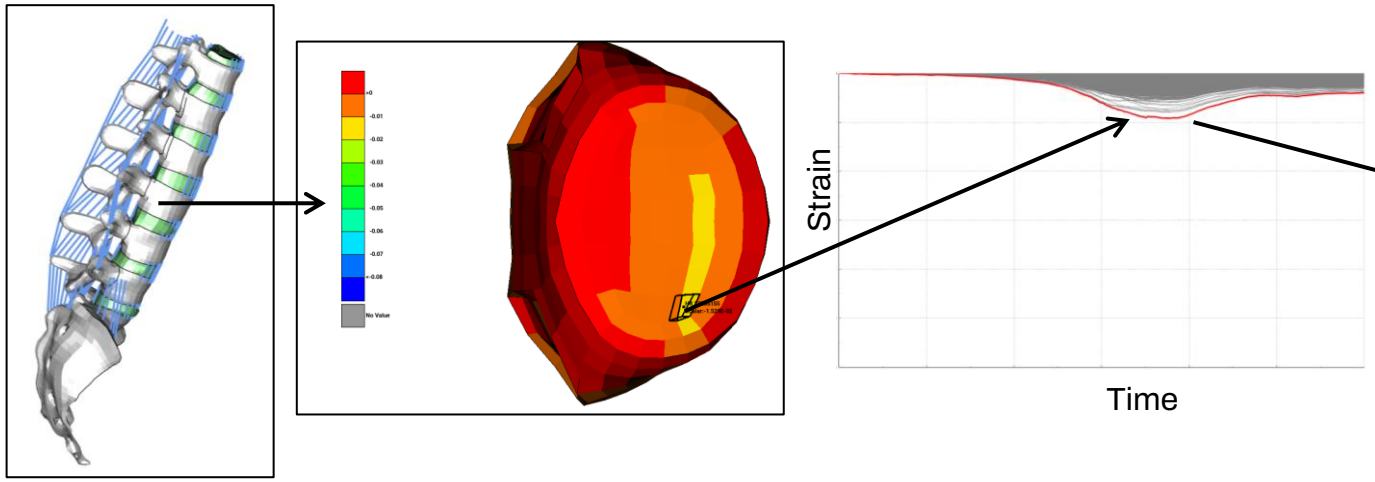
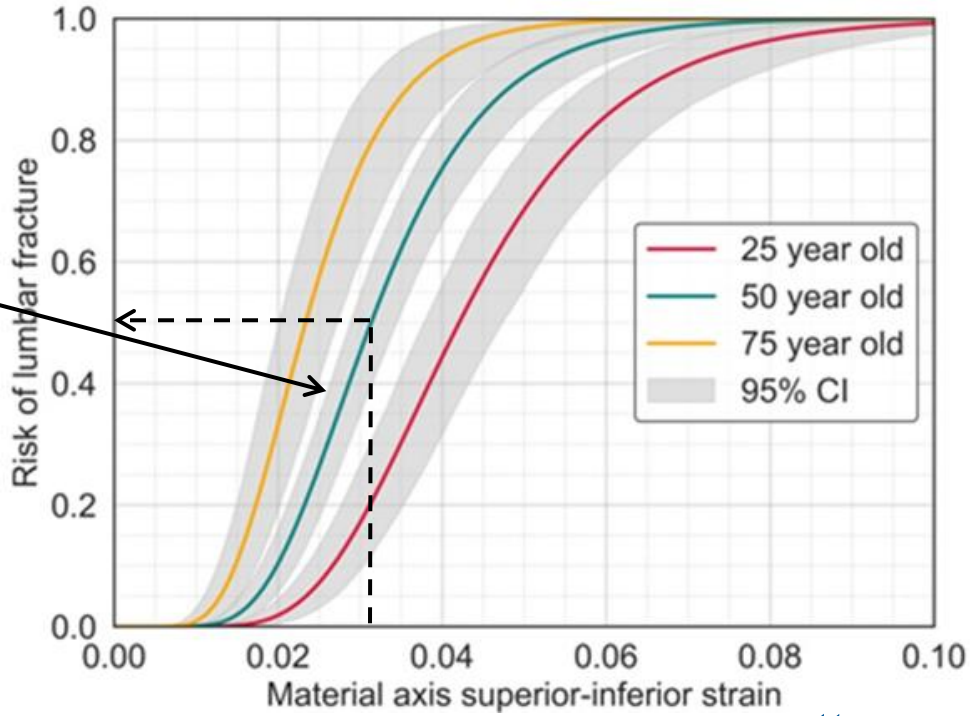
Background: Lumbar Spine Vertebra Fracture Assessment

- Lumbar spine vertebral body fracture in SAFER HBM is assessed by prediction of endplate fracture onset based on trabecular bone inferior-superior peak strain (Iraeus et al. 2023)
  - With an associated tissue-level age-dependent injury risk function





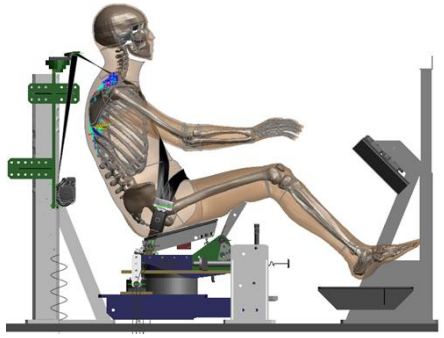


Iraeus, J. et al. (2023) A new open-source finite element lumbar spine model, its tuning and validation, and development of a tissue-based injury risk function for compression fractures. Proc. IRCOBI Conference.

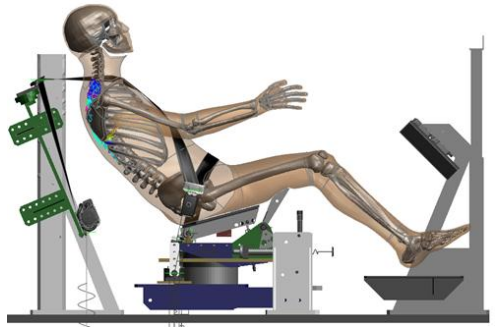
Objective

- Evaluate the upper-body kinematic response of the mid-sized male SAFER HBM
  - By means of biomechanical data from frontal post-mortem human subject (PMHS) crash tests
  - ENOP seating Positions

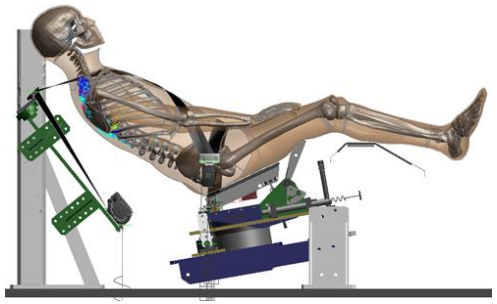
- Investigate the effect of increased seat recline on thoracic spine loading
  - SAFER HBM predicted vertebra cross-sectional compression forces and flexion moments
  - SAFER HBM predicted vertebra fracture risks (exploratory assessment)



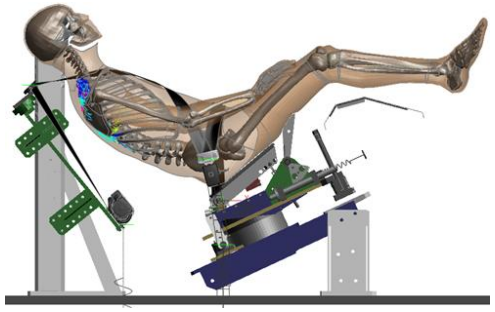
Upright SP1
Seat pan 15°, Seat back 22°



Reclined SP2
Seat pan 15°, Seat back 45°



Deep reclined SP4
Seat pan 25°, Seat back 60°



Deep reclined SP5
Seat pan 40°, Seat back 60°

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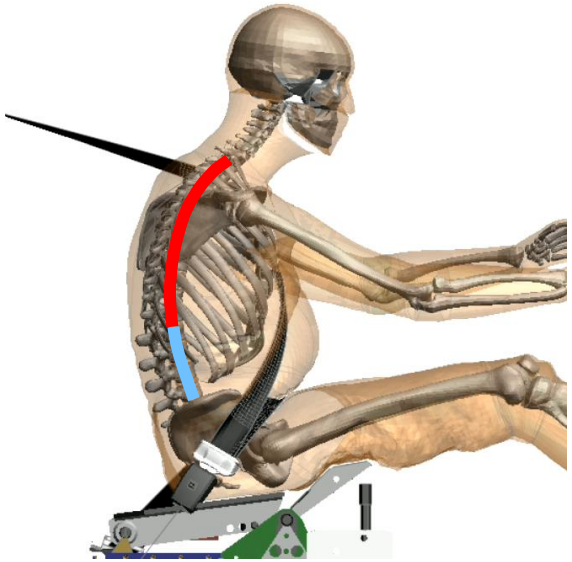
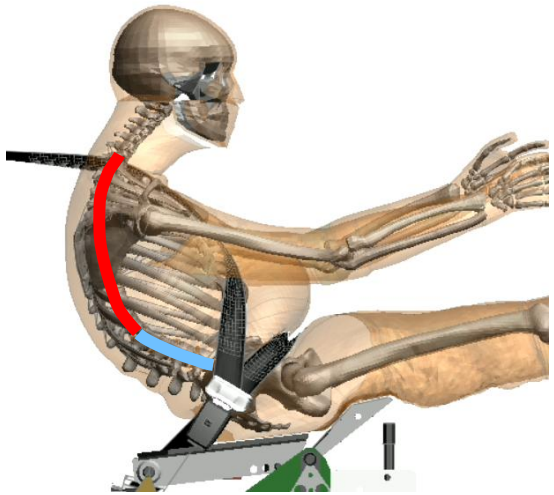
Spine Deformations at the Time of Peak Loading (70-80 ms)

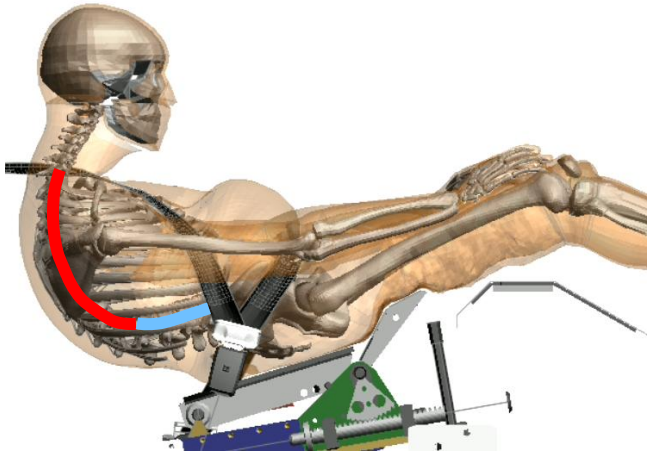
SP1
Upright
15°/22°

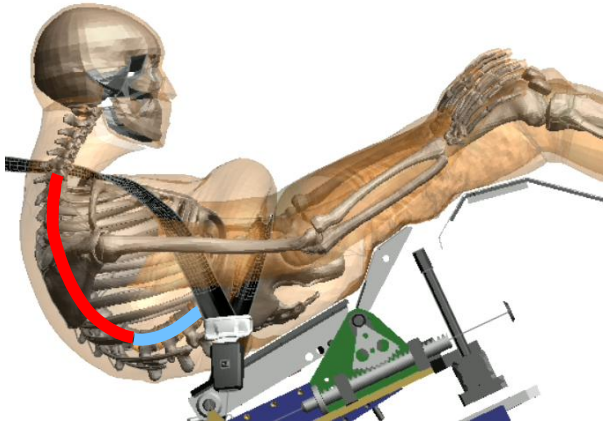




SP2
Recline
15°/45°

SP4
Deep recline
25°/60°



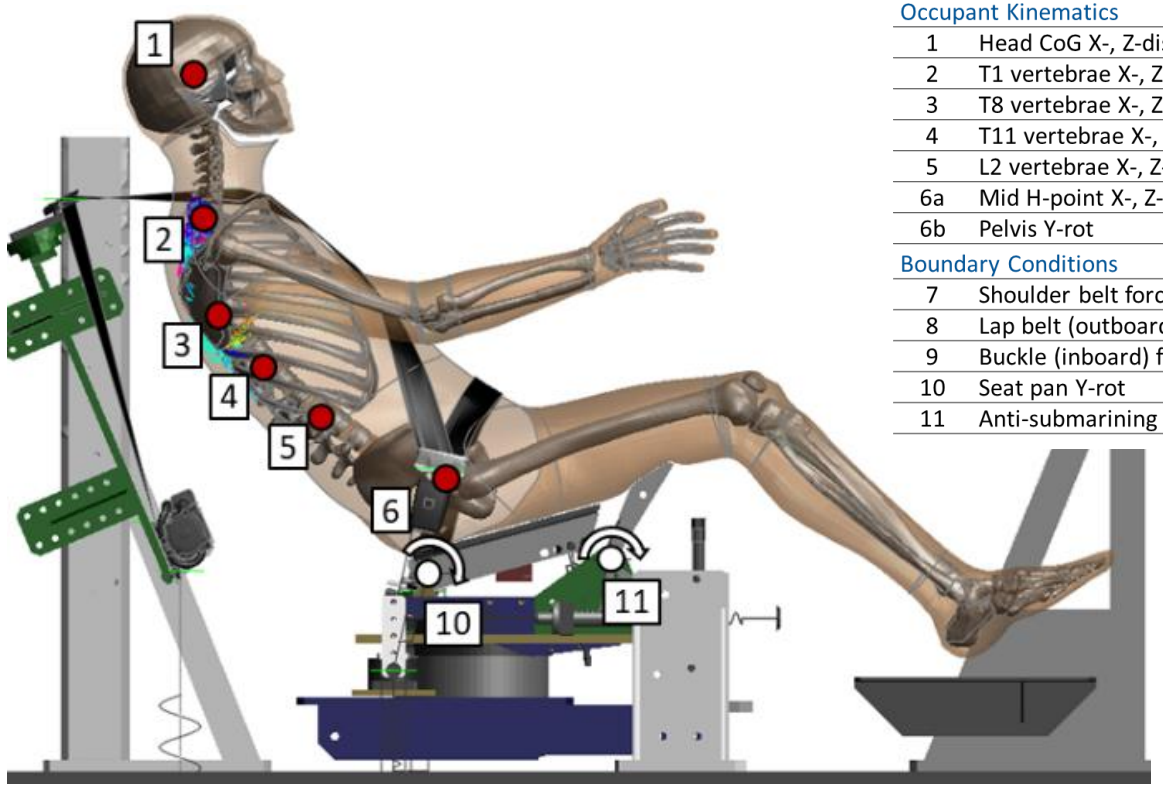


SP5
Deep recline
40°/60°

Thoracic spine
Lumbar spine

SAFER HBM Correlation to ENOP PMHS Tests

- ISO/TS-18571 rating method:
  - Boundary conditions score: Seat and Seatbelt
  - Occupant kinematics score
  - Total score
- 18 time-history channels
- ISO-scores averaged across three PMHS for each seating configuration



Num	Measurement
Occupant Kinematics	
1	Head CoG X-, Z-disp
2	T1 vertebrae X-, Z-disp
3	T8 vertebrae X-, Z-disp
4	T11 vertebrae X-, Z-disp
5	L2 vertebrae X-, Z-disp
6a	Mid H-point X-, Z-disp
6b	Pelvis Y-rot
Boundary Conditions	
7	Shoulder belt force
8	Lap belt (outboard) force
9	Buckle (inboard) force
10	Seat pan Y-rot
11	Anti-submarining pan Y-rot

ISO-Score for Occupant Kinematics and Boundary Conditions

- ISO/TS-18571 rating method:
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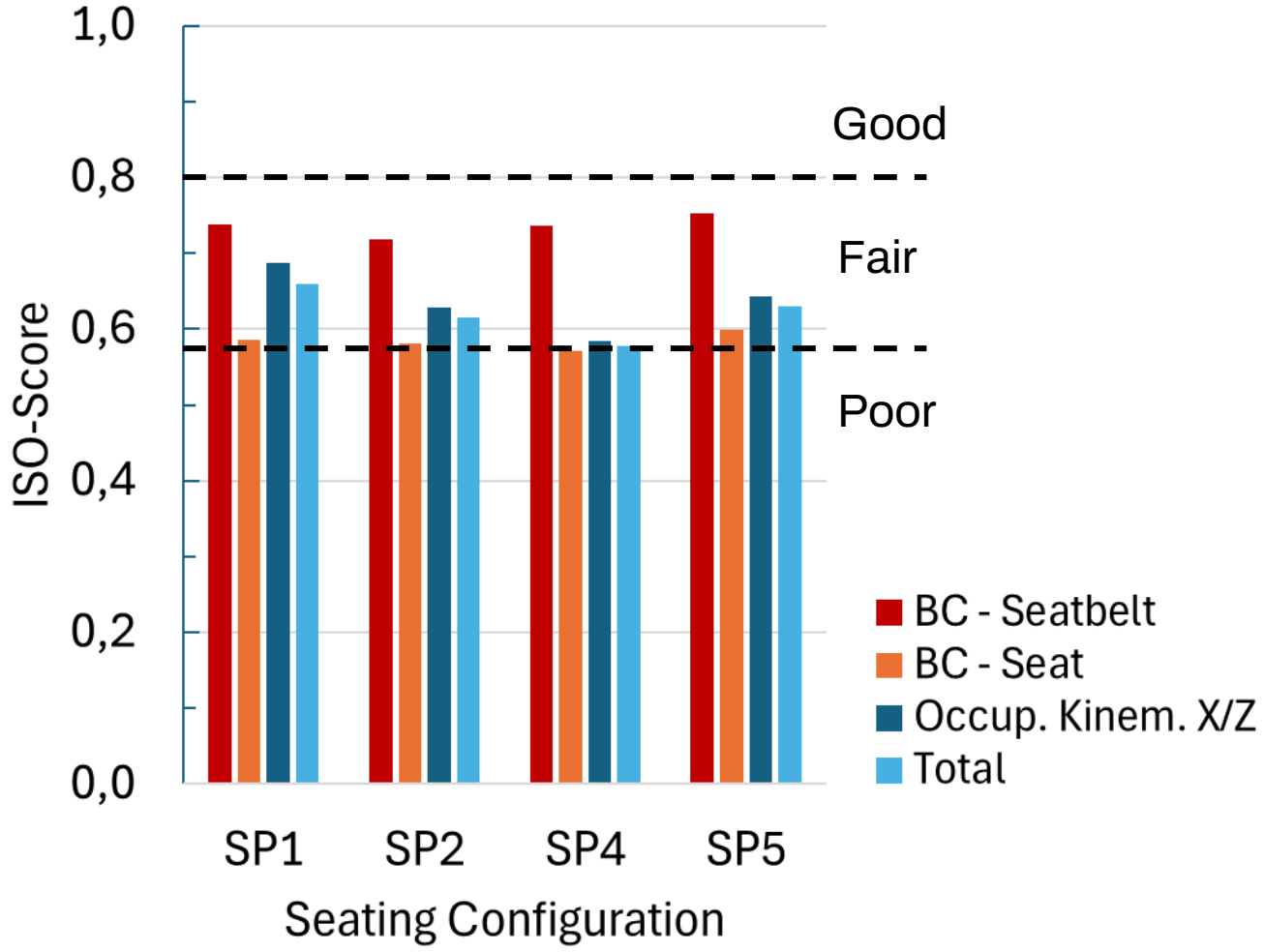
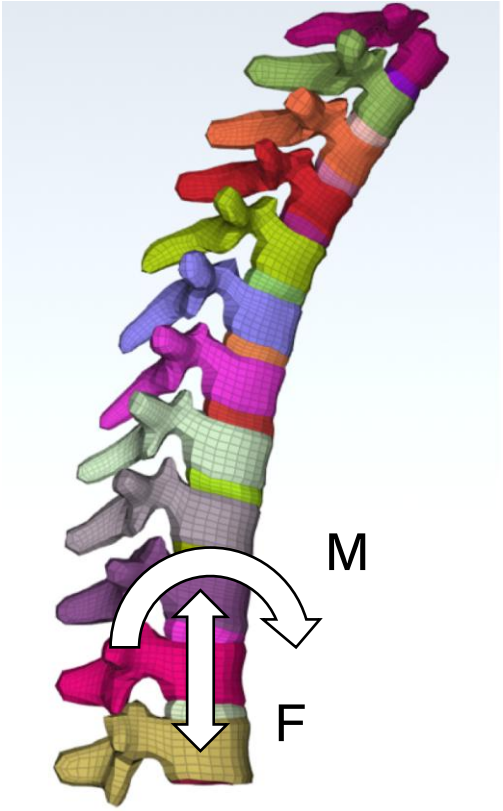
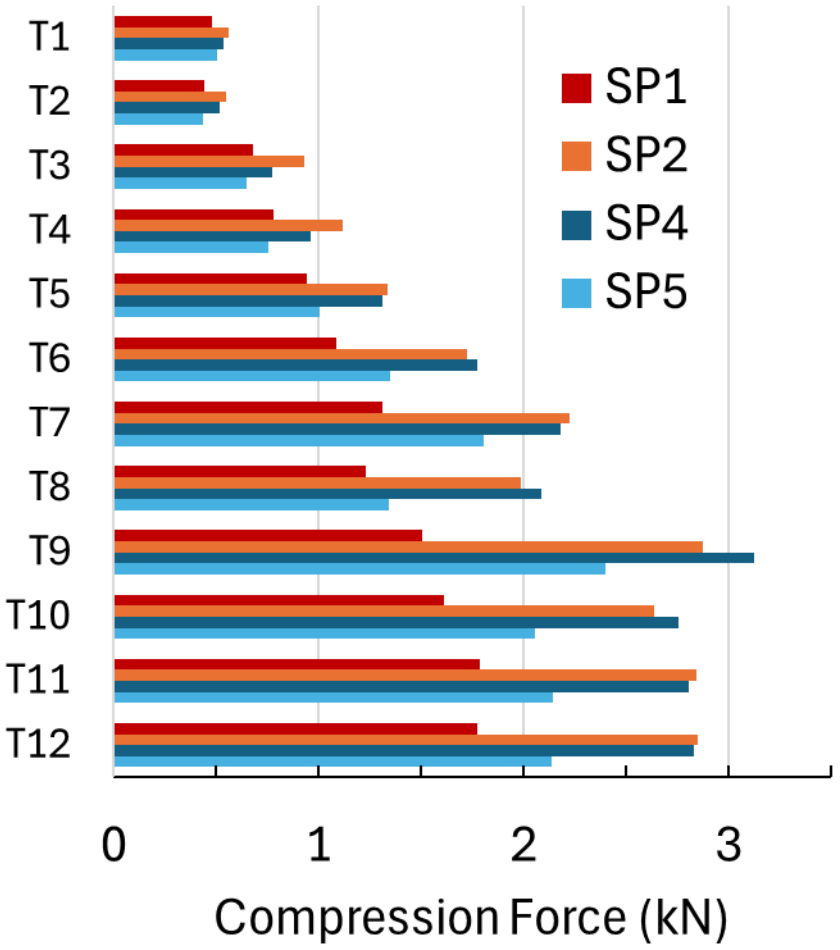
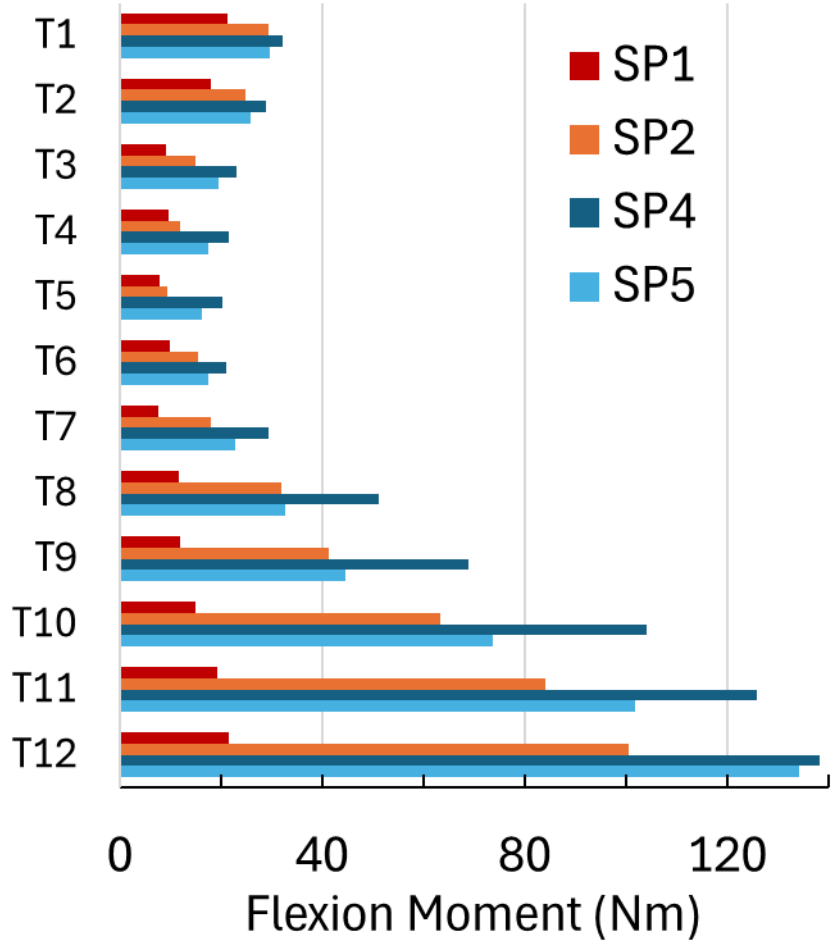


Thoracic Spine Compression Forces and Flexion Moments







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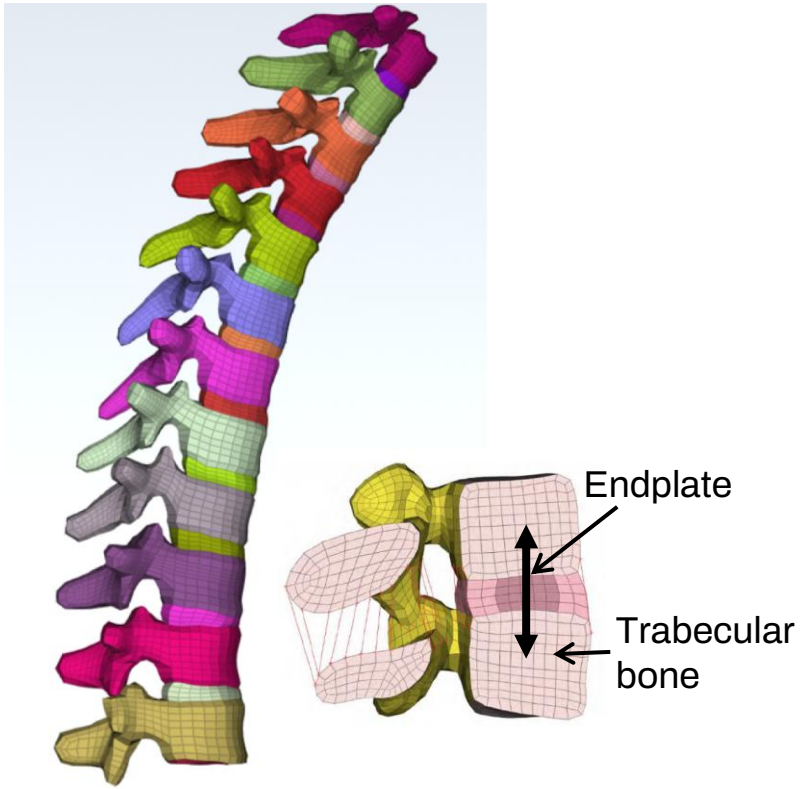
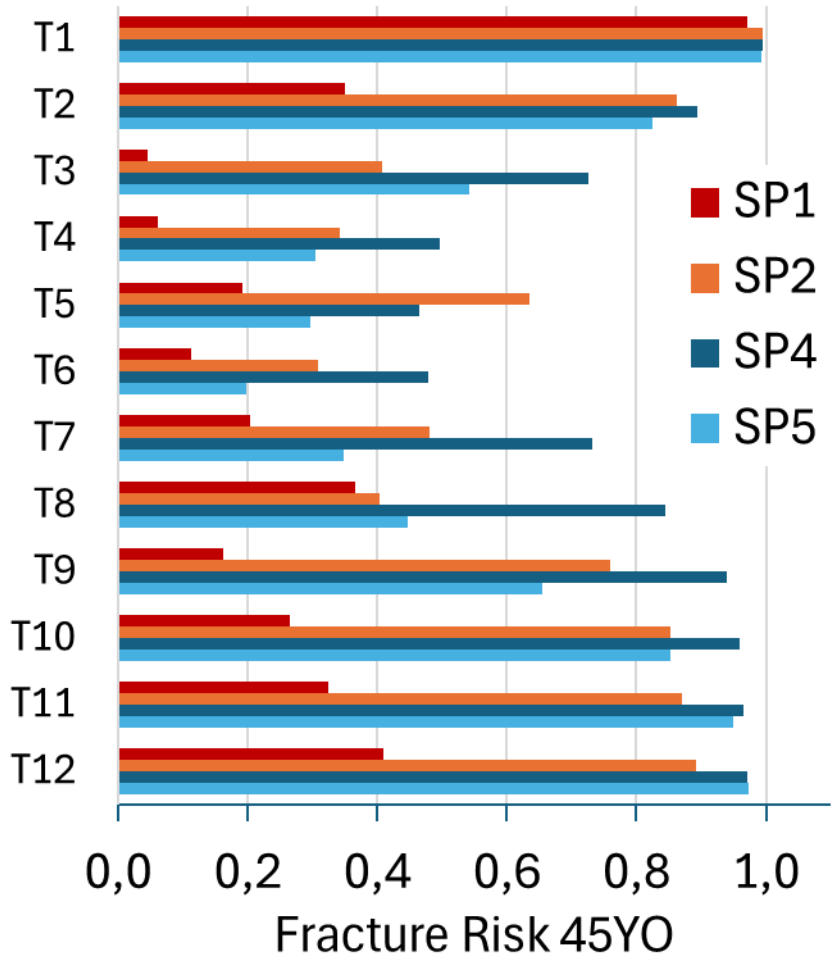
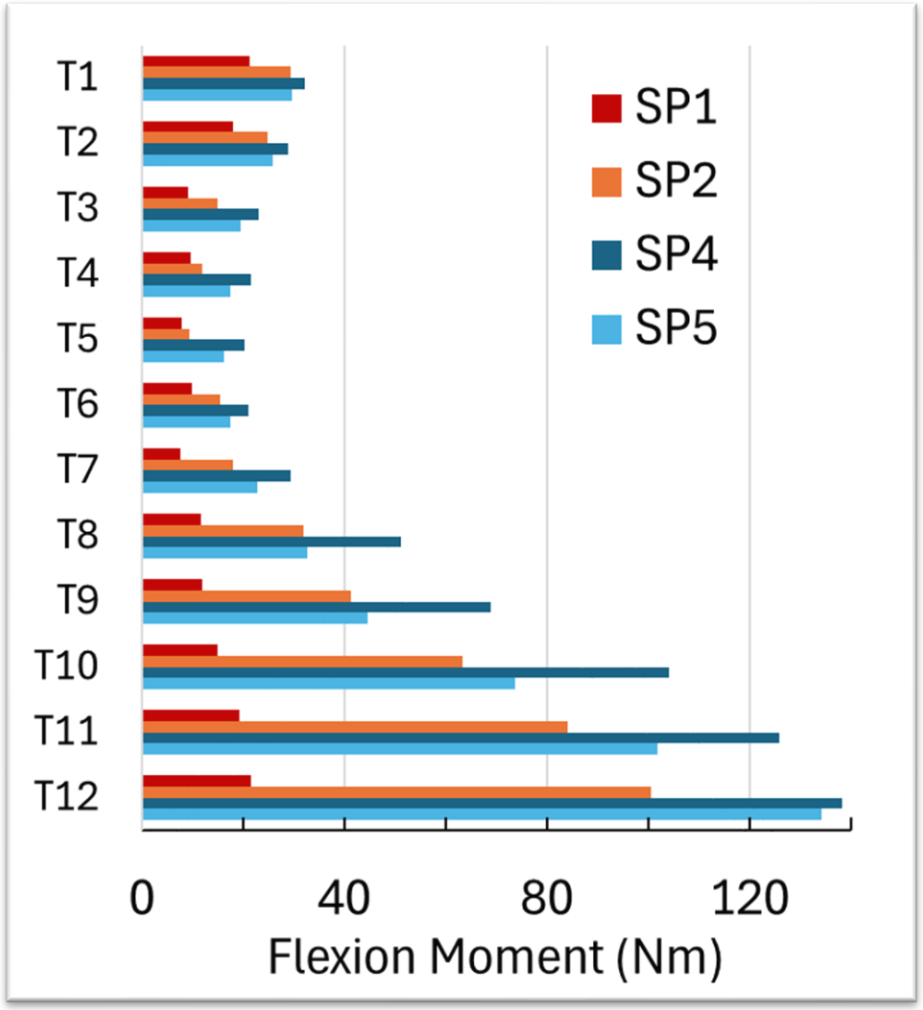
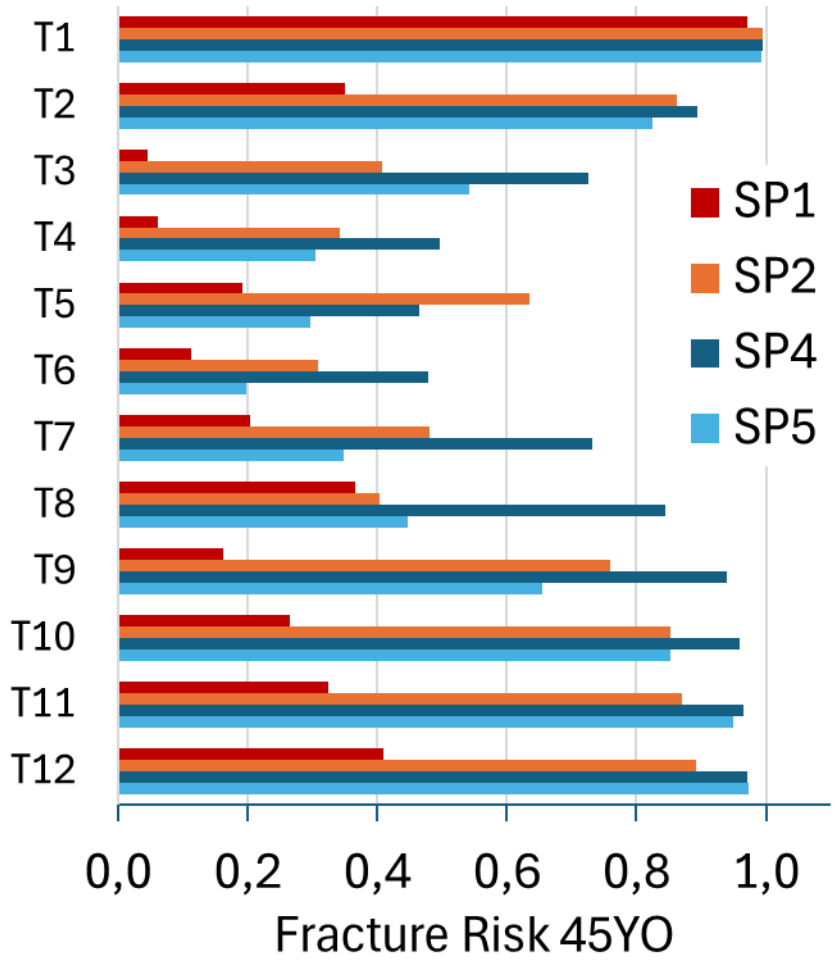
Thoracic Spine Vertebra Fracture Risk





Thoracic Spine Vertebra Fracture Risk vs Flexion Moments





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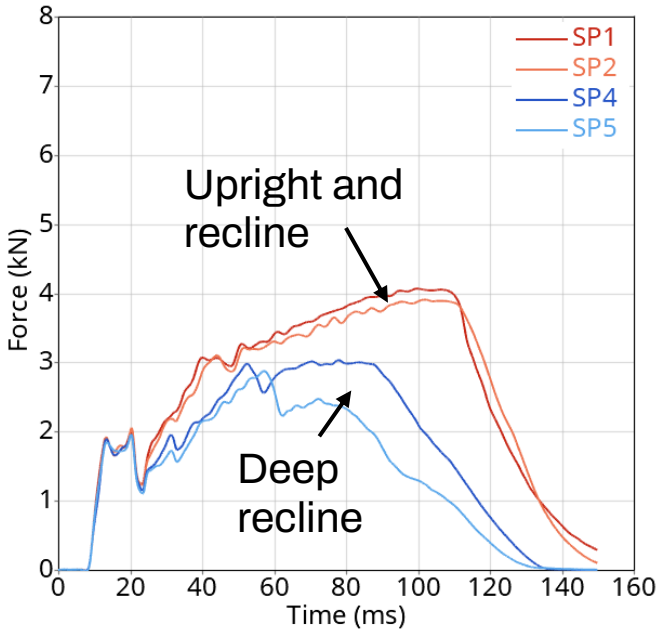
Discussion

- Morphing the mid-sized male SAFER HBM to match individual PMHS anthropometry is expected to improve the correlation (ISO-score)
  - Greater pelvis and femur soft tissue thickness in the HBM affected the interaction with the anti-submarining pan, resulting in higher seat rotations than those observed for the PMHS.
- Averaged reference curves from PMHS may improve the ISO-score
- Deep reclined postures alter kinematics and loading patterns
  - Shoulder belt load limiting force hardly activated
  - Other seat-integrated restraints, such as the seat-track load limiter, may be required



Limitations

- Semi-rigid seat versus a production seat

- SAFER HBM vertebra fracture risk prediction currently only validated by means of lumbar spine reference data
  - Risk assessment conservative – predicts the onset of fracture (Iraeus et al, 2023)
  - Reconstructions of vertical loading scenarios from aircraft seat ejection and underbody blast have also shown high risk predictions (Das, 2025)

Das, A. (2025) Impact Biomechanics of the Thoracic Spine: A Finite Element Human Body Model Validation Study under Vertical Loading Conditions, Master of Science Thesis TRITA-ITM-EX 2025:478, KTH, Stockholm, Sweden

Conclusions

- SAFER HBM in the ENOP reclined seating configurations reproduced key kinematics relevant to assess thoracic spine loading in frontal crash scenarios

- Deep reclined postures alter kinematics and loading patterns, exemplified by the increased thoracic spine loading despite the lower speed
  - New challenges for occupant protection

- An increased thoracic fracture risk was predicted for (deep) recline compared to upright. However, more work needed to further improve thoracic spine injury assessment:
  - PMHS thoracic spine test reference data in compression/flexion loading needed
  - Thoracic spine is more complex than lumbar spine – better understanding of the influence from the connected rib cage needed