



An approach to compare the submarining behavior of THUMS vs. THOR

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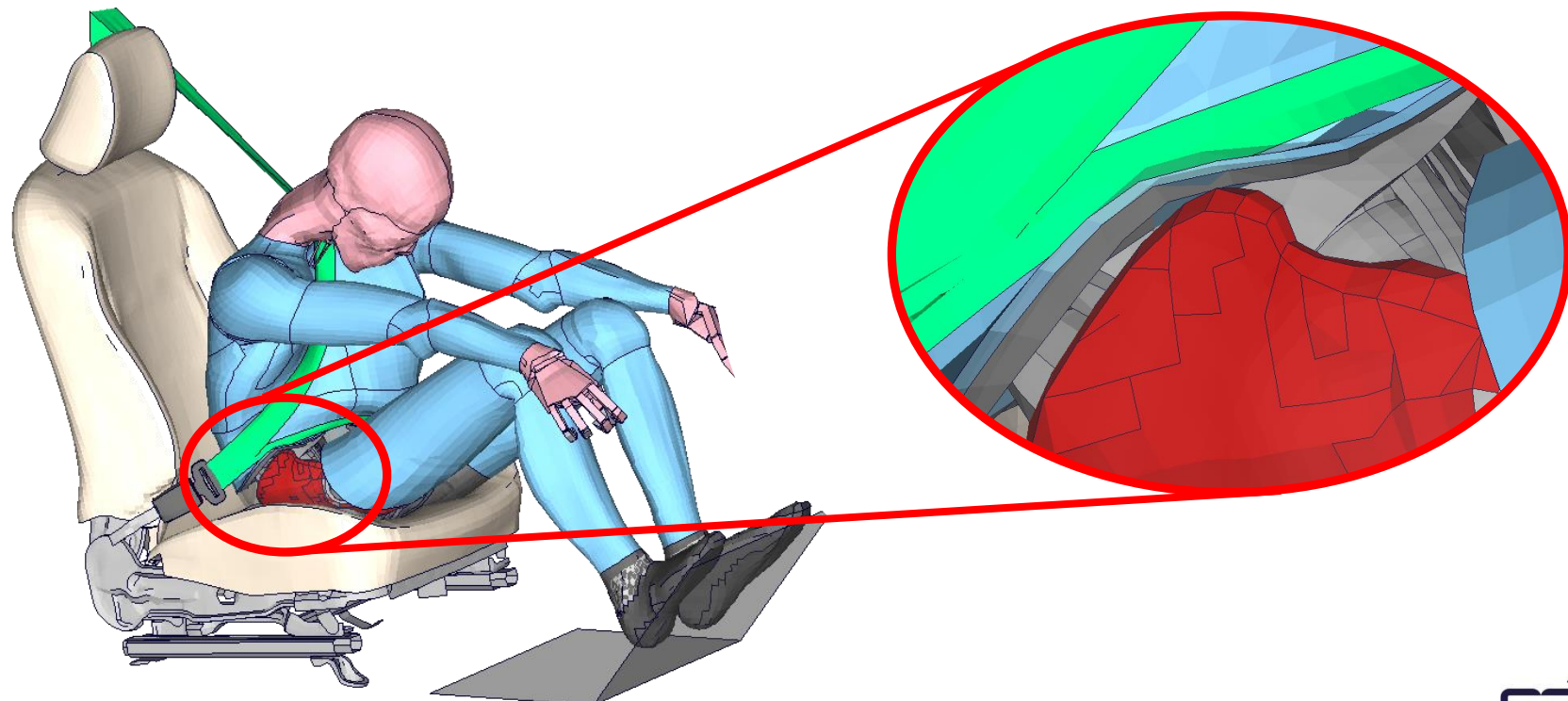
Overview

- Submarining
- Description of the FE-Models
- Design of the Study
- Findings
- Summary



Submarining

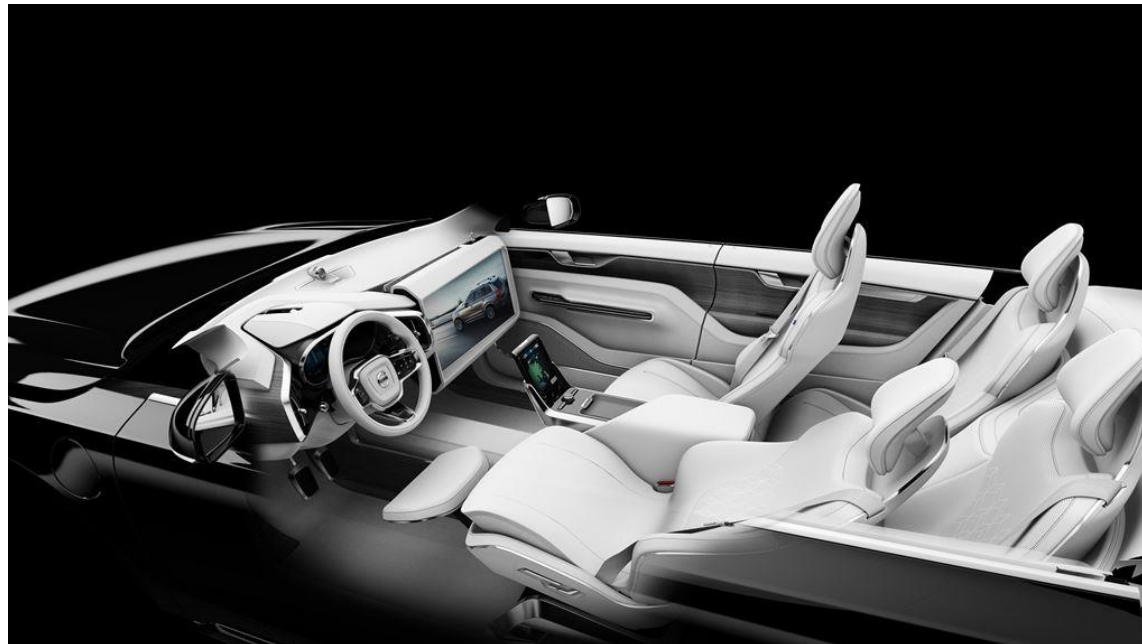
- Submarining occurs, when the lap belt slips off the iliac and penetrates the abdomen, resulting in serious injuries of the inner organs even lumbar spine.
- With no submarining the belt forces are led into the skeleton during crash. While the iliac crest retains the lap belt.





Submarining

- 5 percentile (women) and children have a higher risk of submarining, because of their smaller size in standard seating position.
- Future developments regarding higher comfort for back seat passengers or occupants in autonomous vehicles also come into focus.

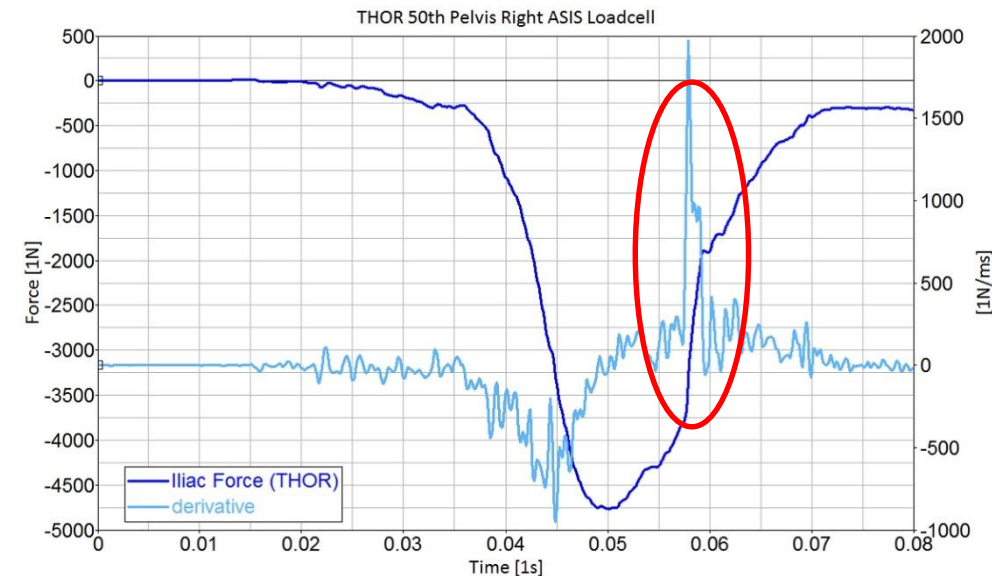
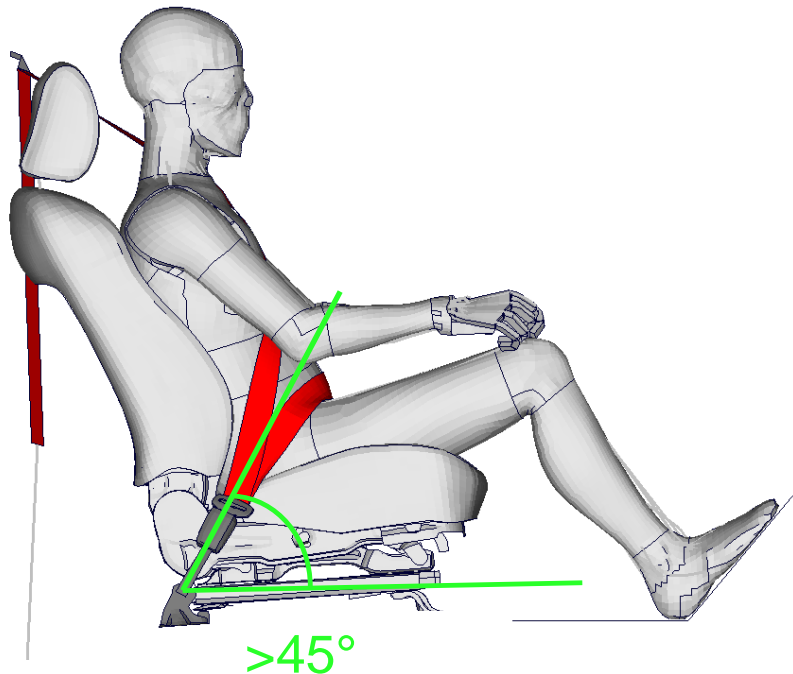


Source: www.volvocars.com, 2016



Submarining

- Several proceedings for evaluation of submarining are known:
 - *Geometric estimation* ($<45^\circ$)
 - *Iliac Force change* (1kN/1ms, H305) (EuroNCAP, 2014)
 - *Slow motion visual assessment*





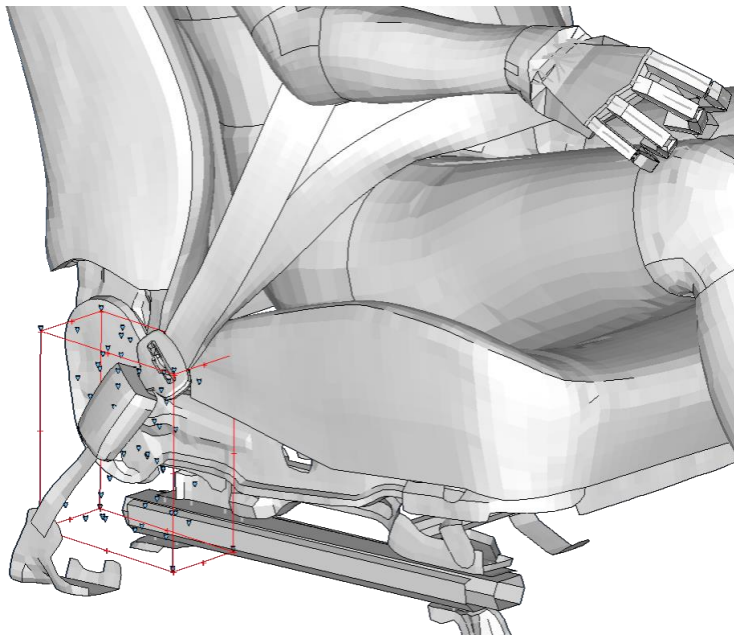
Design of the Study

- To determine the submarining behavior of a test subject, following boundary conditions can be varied:
 - *Seating Position: upright or slouched*
 - *Seat Cushion: adjusted foam stiffness*
 - *Restraint System: adjusted pretensioner and load limiter*
 - *Seat Belt Routing: variation of the fixed points*

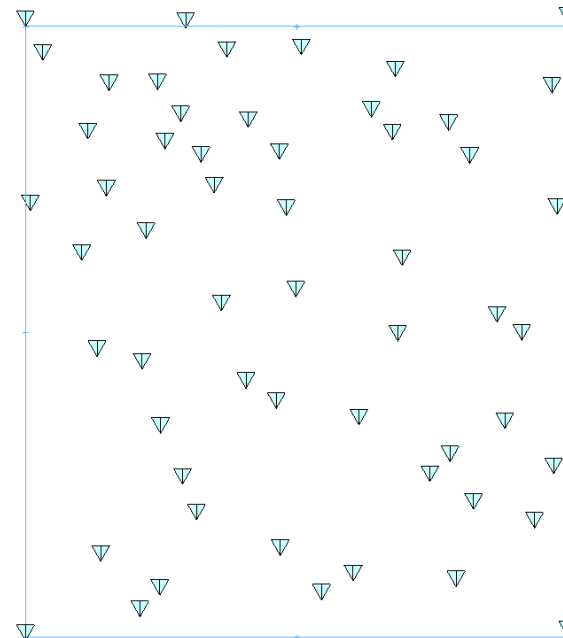


Design of the Study

- Variation of the buckle position to determine the threshold between submarining and non submarining.
- 68 random positions for each test object including the corners.
- The design space measures 150x70x170mm
- After 30 runs redefining of the remaining positions within the range of the possible threshold.



THUMS design space



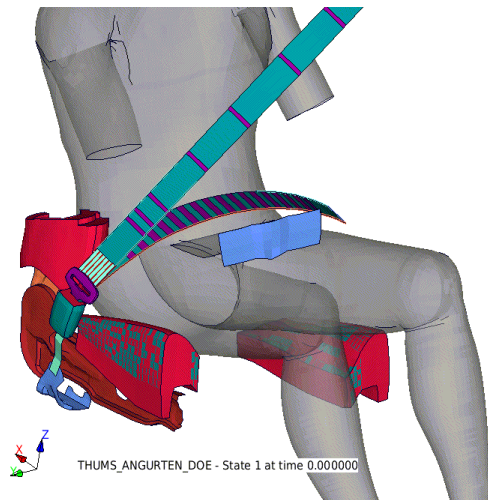
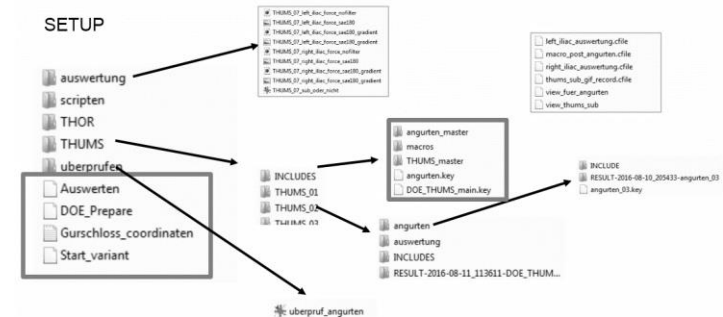
THOR design space



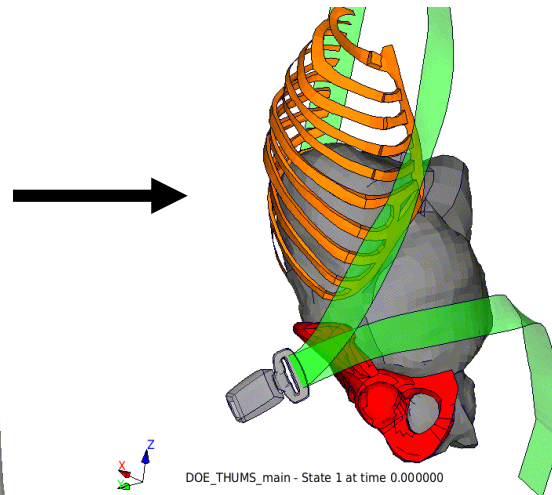


Design of the Study

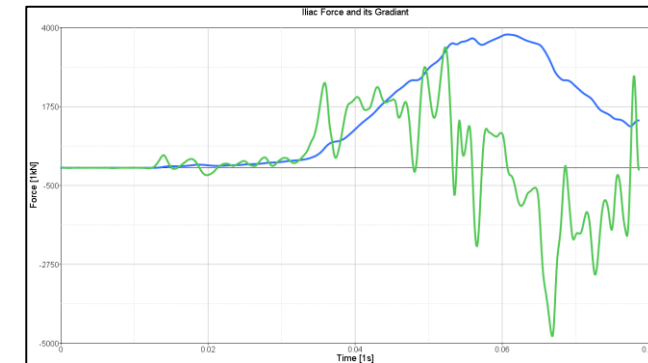
- A pre-simulation is developed in order to demonstrate belting and related seat foam deformations.
- Whole process is carried out with the help of in-house scripts, including belting and result evaluation.



Pre-Simulation



Crash Simulation



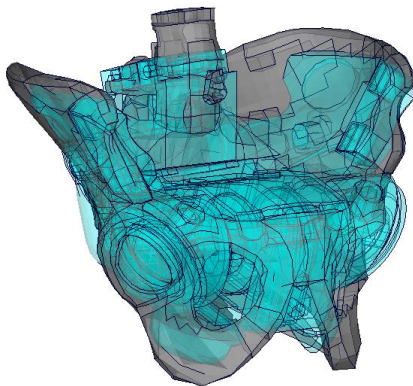
Results



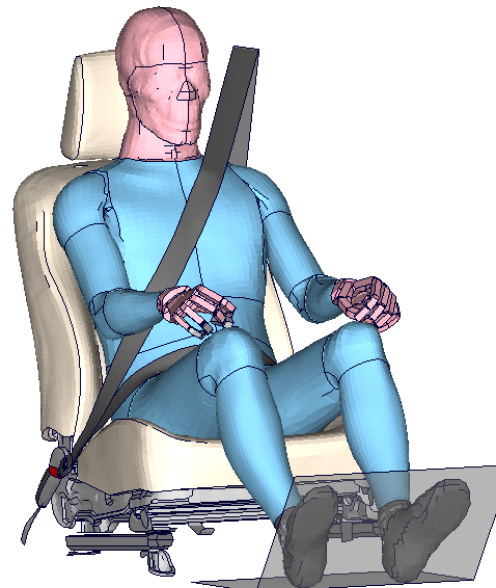
Description of the FE-Model

- LS-Dyna R7.1.2
- Modified Toyota Yaris Seat model
- Generic Retractor Pretensioner and Load limiter (6,5kN)
- Generic Seating Position and Pulse based on Literature (Richard et al., 2015)

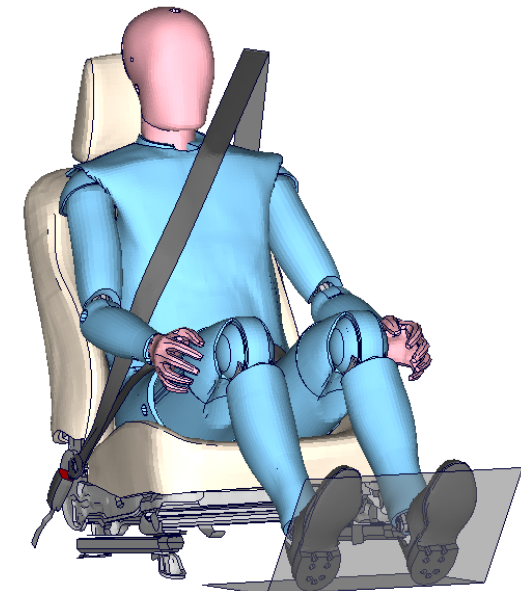
aligned h-point and
pelvic angle



THUMS V5.0 (no fracture)

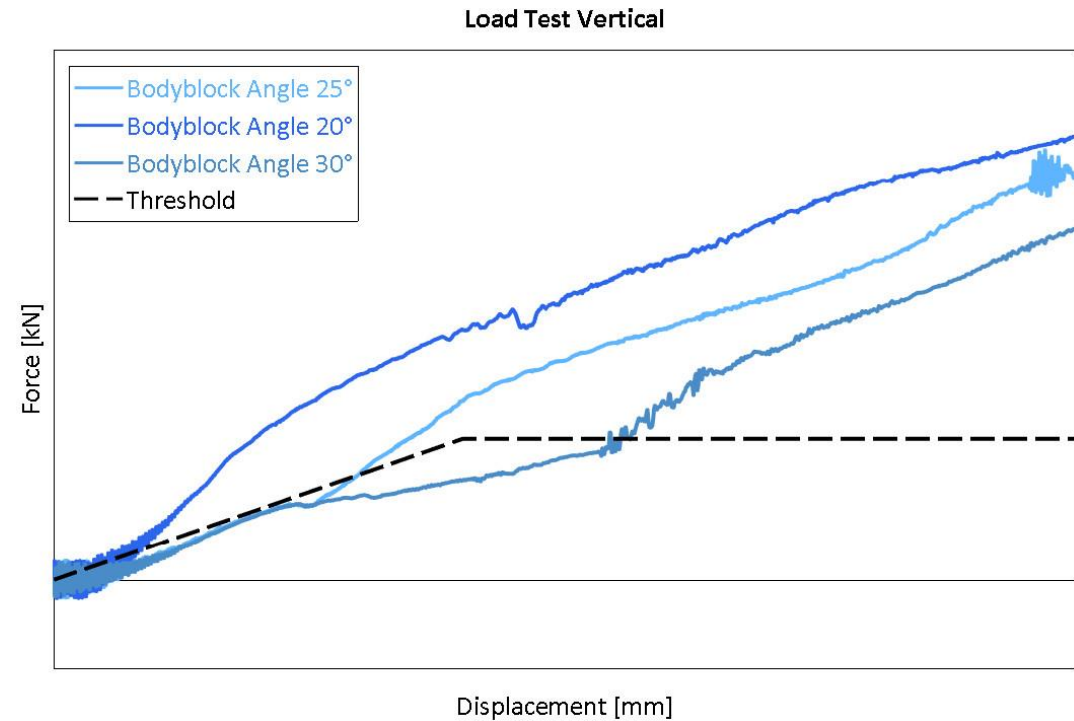
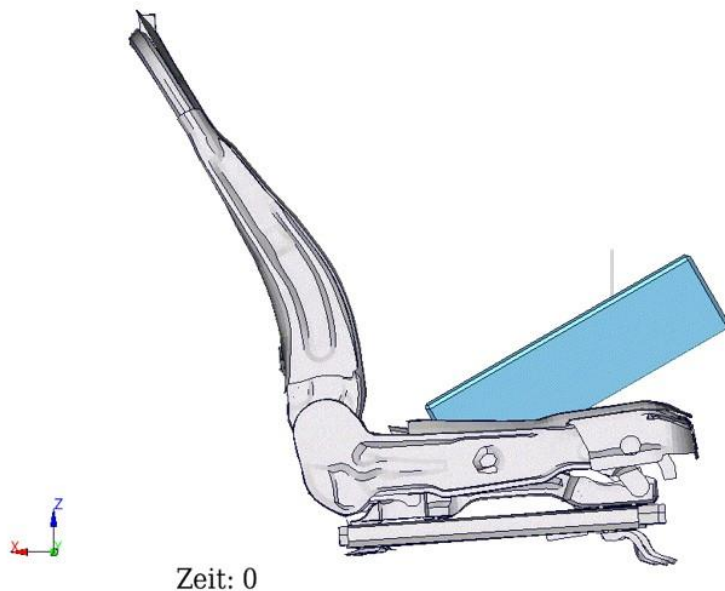


THOR 50th V1.0.1_S2



Description of the FE-Model

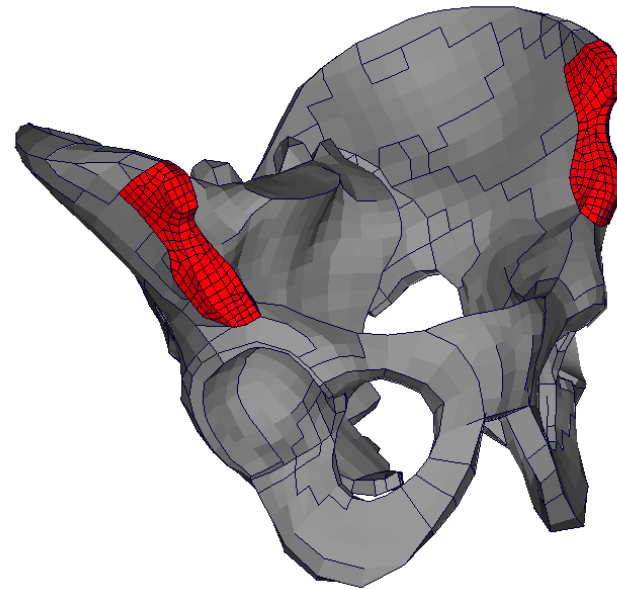
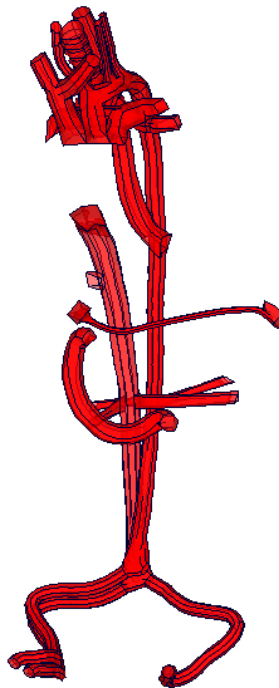
- Modified seat model matching OEM Standards
- Original seat structure was slightly weak
- For standard anti submerging behavior, seat-ramp and supporting structural elements were stiffened





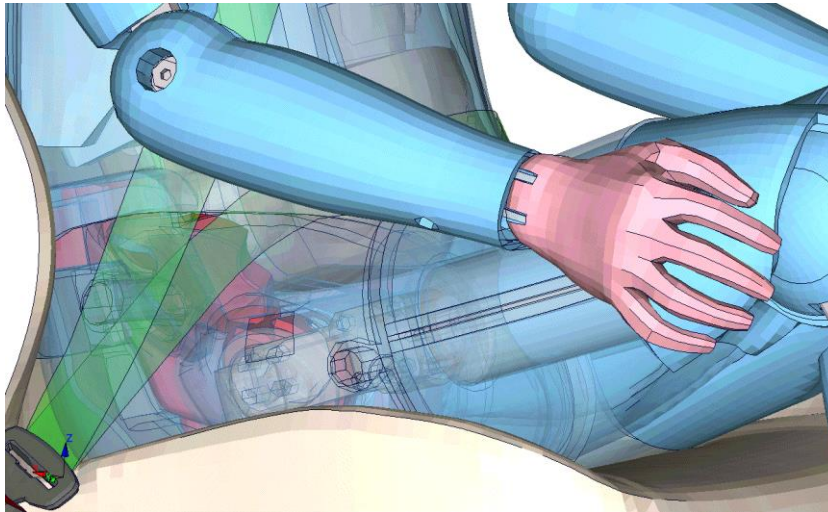
Description of the FE-Model

- In order to avoid excessively distorted elements, inner canals of THUMS (main arteries, aorta, etc.) are modified and proved that modifications does not effect the kinematic behavior.
- Force sensor for iliac crest of THUMS is developed and used in order to provide an better understanding of the complex kinematics of the submarining phenomenon.

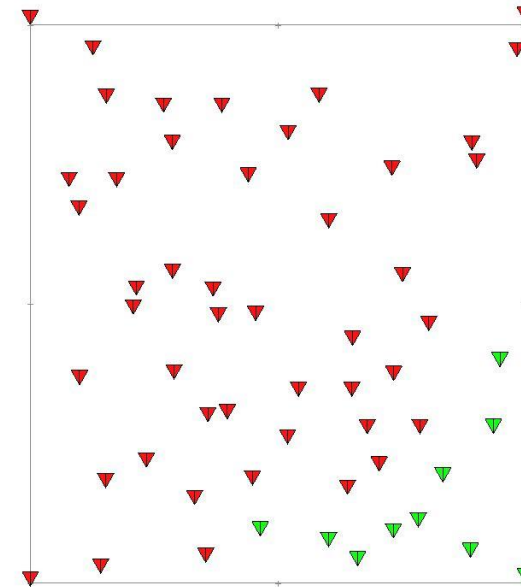
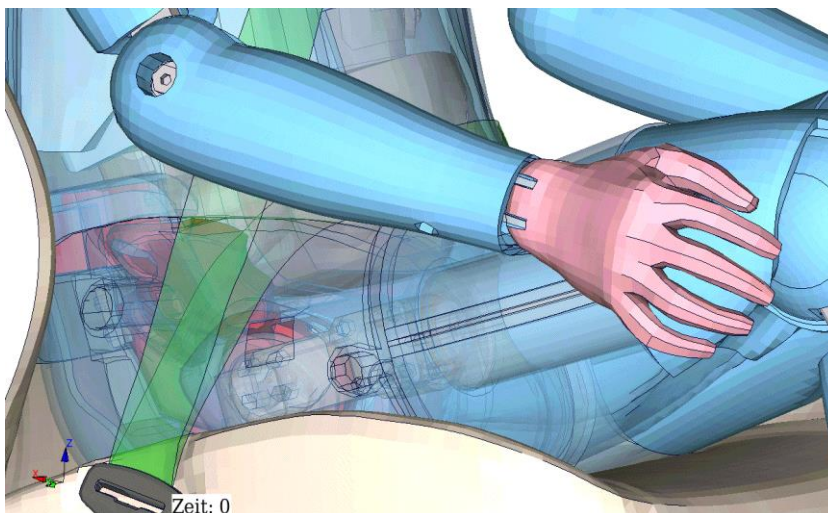


Findings

• THOR showing Submarining



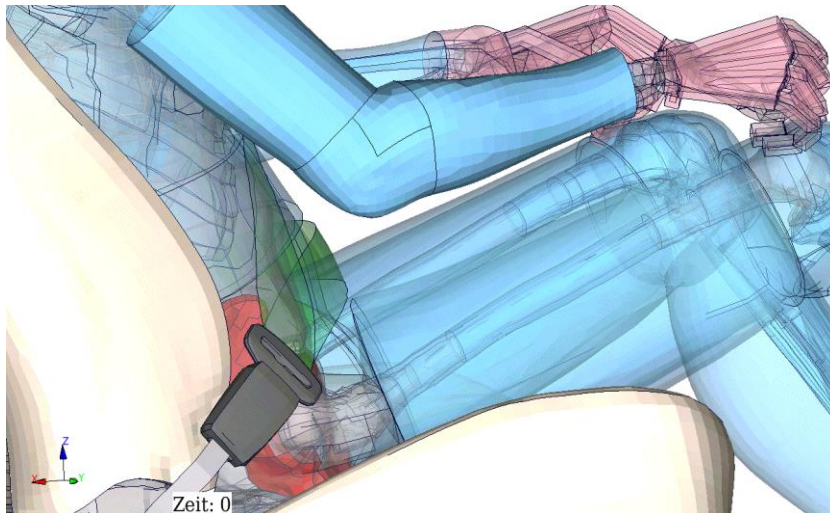
• THOR showing no Submarining



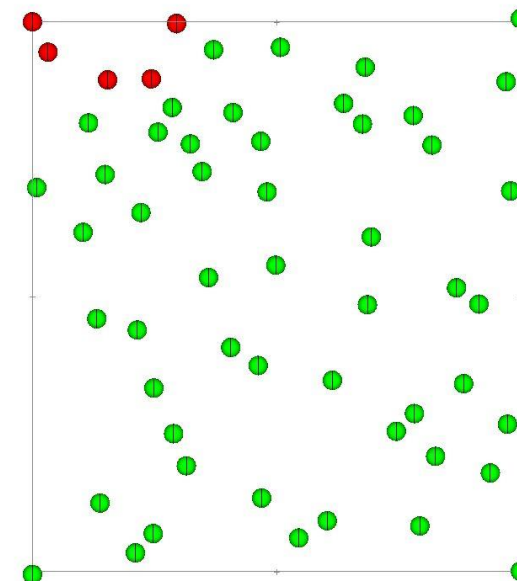
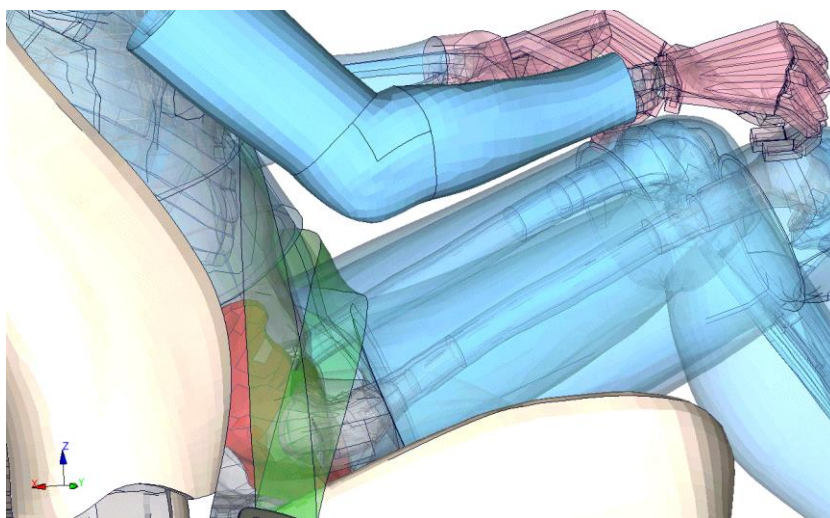
- The THOR Dummy tends to show submarining in most of the cases.
- The lowermost front positions do not show submarining.
- The lap belt cannot hold up the iliacs if the buckle position is too high.
- The pelvis foam covers the iliacs in the direction of the femur.
- So the lap belt can slip off the iliacs more easily.

Findings

- THUMS showing Submarining

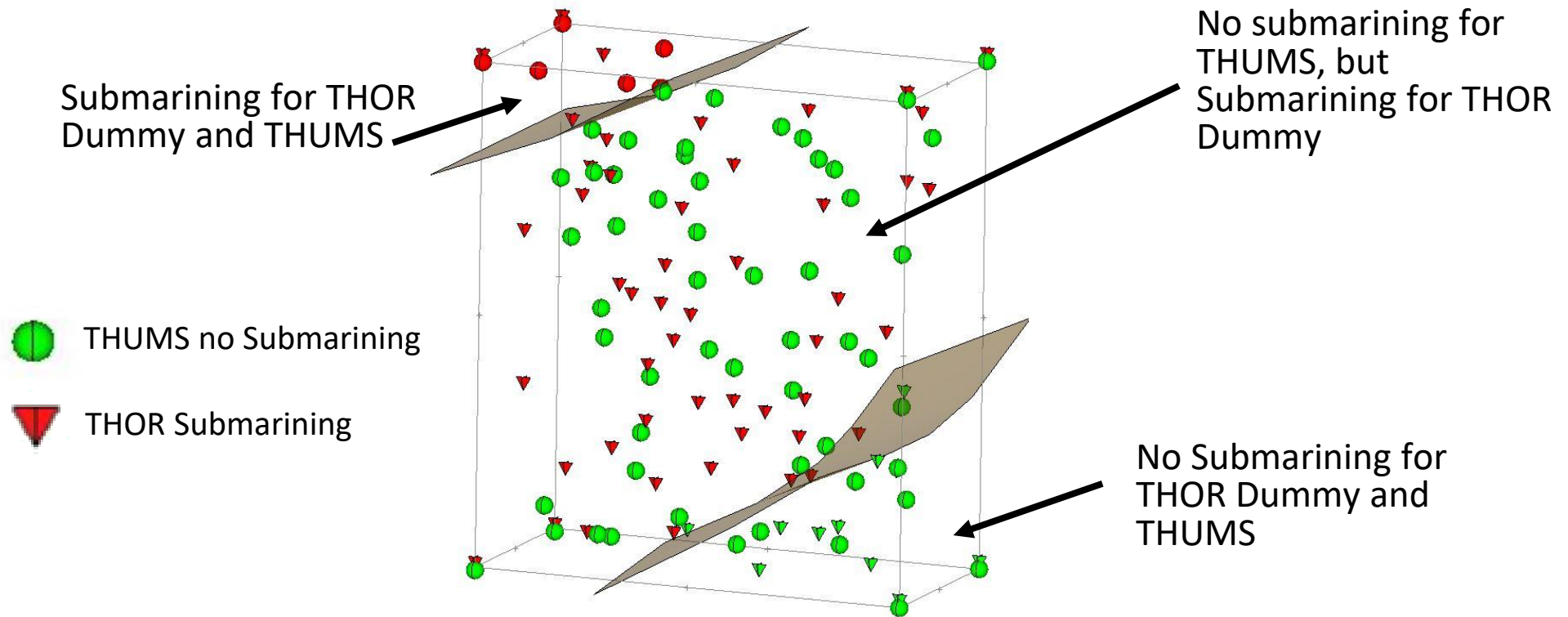


- THUMS showing no Submarining



- The THUMS has a significant lower tendency to show submarining.
- The upper buckle positions lead to submarining.
- Although the pelvis rotation is very high, comparing to the THOR Dummy, very few submarining is observed.
- In some cases the lower ribs slide behind the iliac, so the lap belt cannot slip off the iliac crest.

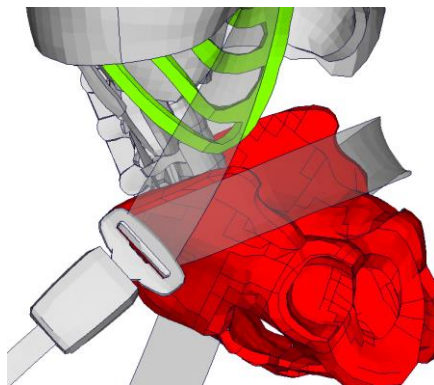
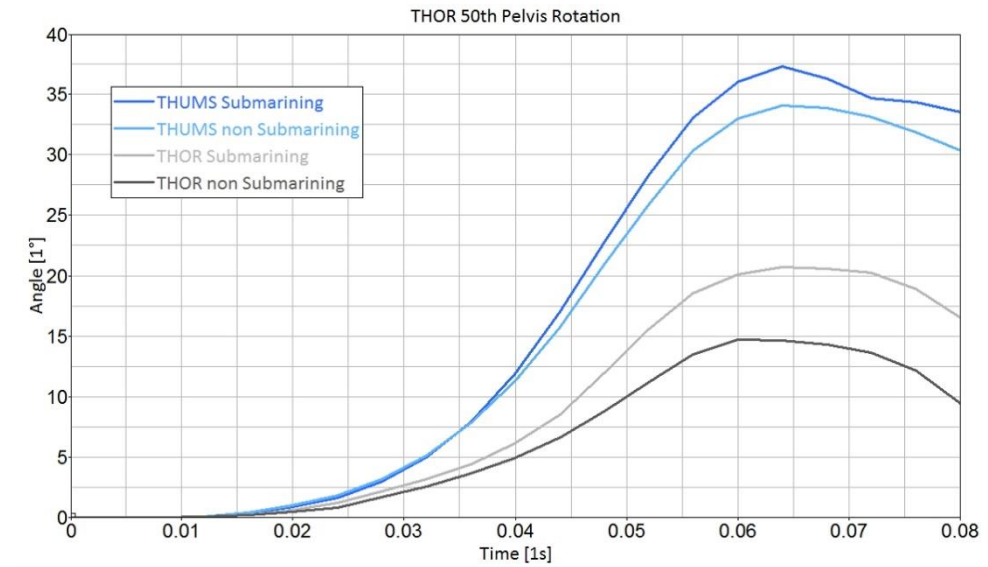
Findings



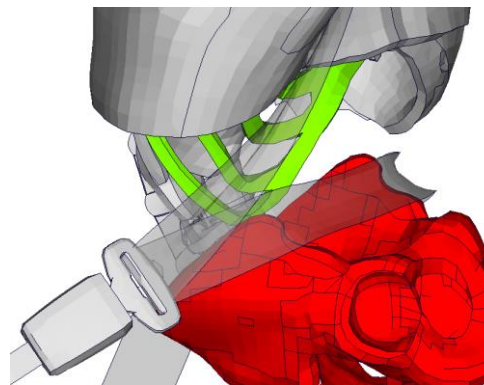
- The difference between submarining areas for THUMS and THOR Dummy are significant.
- Only the lowermost front positions of the design space both test subjects do not tend to exhibit submarining.
- In most of the cases submarining occurs for the THOR Dummy.
- Only few cases showed submarining for the THUMS.

Findings

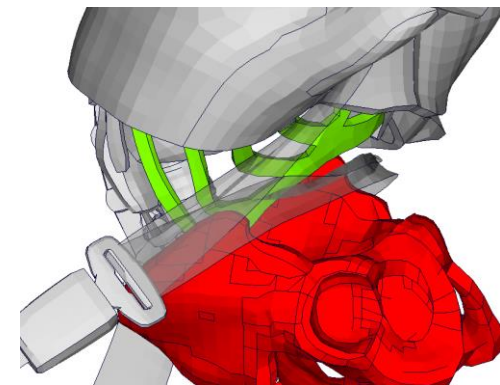
- As mentioned in the literature the standard FE THOR model has less pelvic rotation because of the stiff lumbar spine and inner contacts.
(Richard et al., 2015)
- Although THUMS pelvis rotation is much higher, the submarining tendency is significantly lower.
- The lower ribs move behind the iliac crest and avoid slipping of the belt from the iliac.



t=30ms

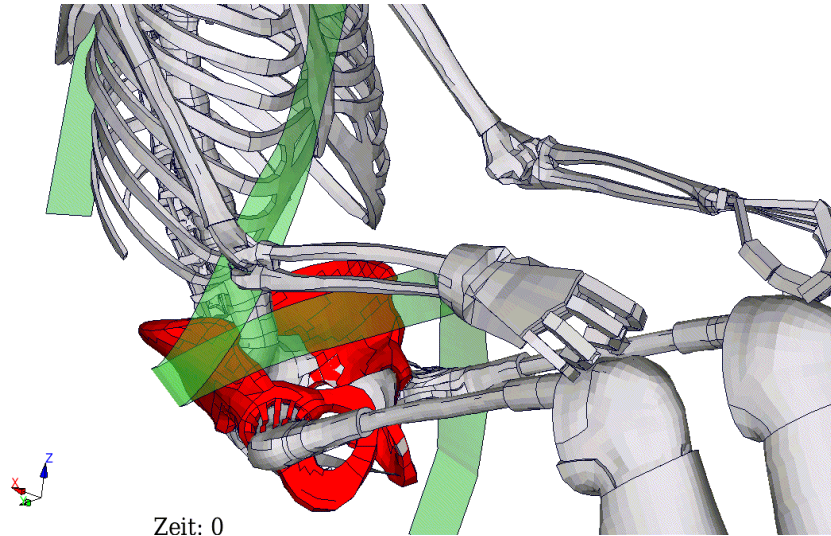


t=55ms



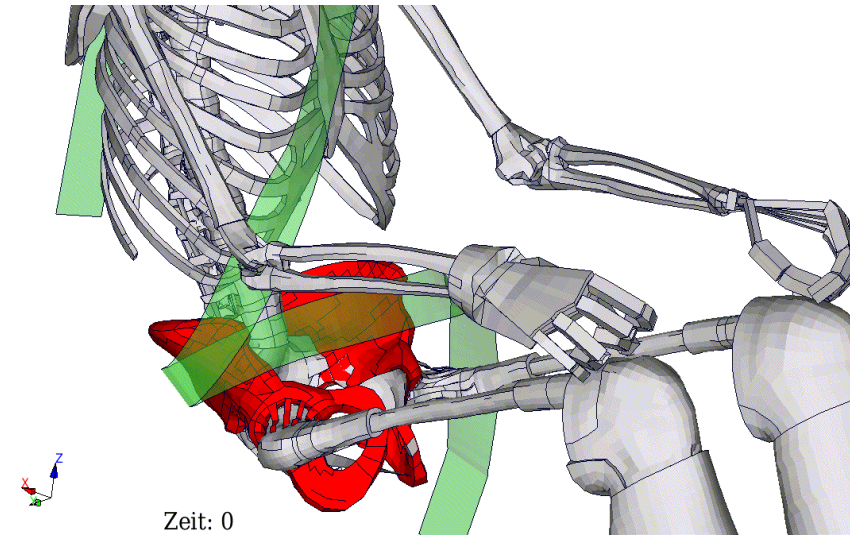
t=75ms

Findings



Zeit: 0

no fracture



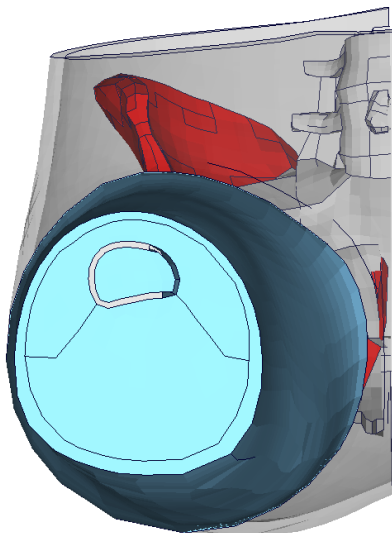
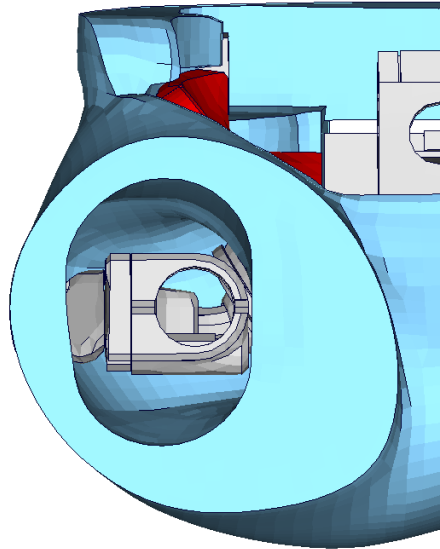
Zeit: 0

fracture with submarining

- Some cases on the border between submarining/no submarining, were reviewed with fracture criteria to get a more reliable submarining area for the THUMS.
- If rib fracture occurs due to the thorax belt loading, the lap belt will more easily slip off the iliacs. Just one case with fracture lead to additional submarining.
- No fracture on pelvic bone appeared.

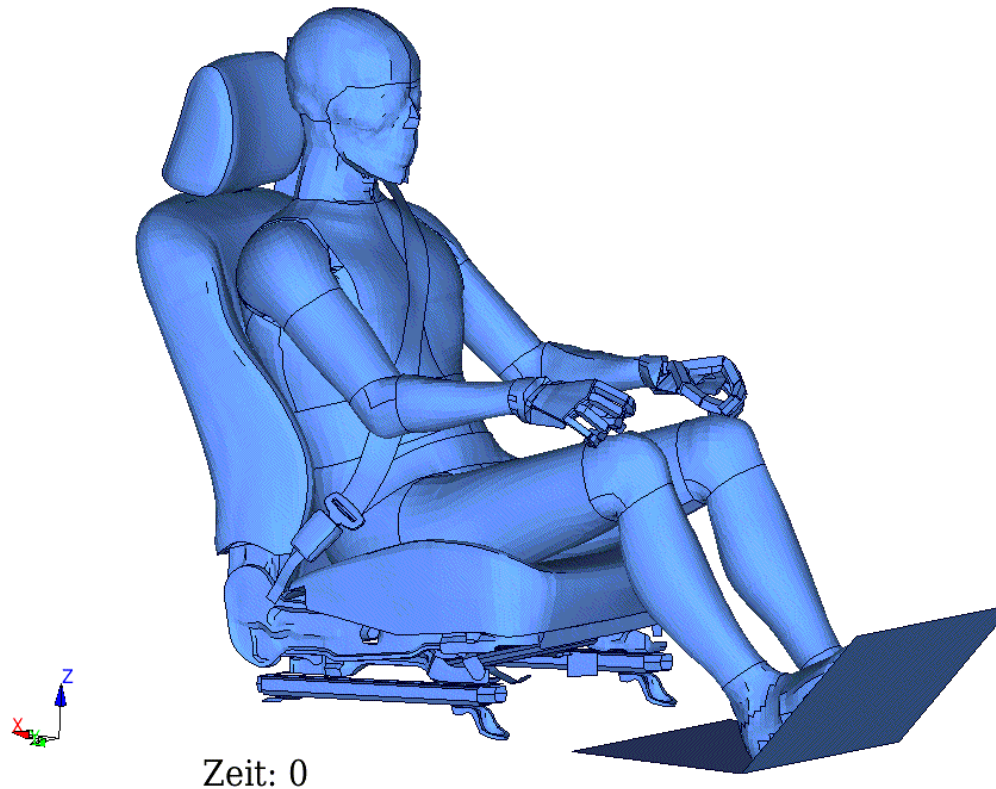


Findings



- The THOR iliac is much more covered by the pelvis foam. Therefore the initial position of the lap belt during the belting pre simulation is higher compared to the THUMS.
- The transition area between femur and pelvis flesh on the THUMS is lower comparing to the THOR.
- Submarining can occur rarely, because of geometric differences to the THOR.

Findings



- As expected activated muscle tonus (red) does not have an impact on the results.
- The human strength is too weak to change the trajectory due to a car crash pulse.



Summary

- Seat belts are one of the most effective safety systems for occupants.
- In some cases the lap belt can slip off the iliac wings and submarining occurs.
- To reveal the differences between FE models of an anthropomorphic test device and a real occupant, 120 buckle positions were simulated to show the submarining behavior of the THUMS and the THOR Dummy.
- The THOR Dummy tends to show more submarining than the THUMS.
- Because of geometric differences of the pelvis flesh and the instance that the lower ribs move behind the iliac wings, the THUMS hardly shows submarining.
- With bone fracture, some buckle positions at the threshold between submarining and non submarining could lead to additional submarining, because the supporting factor of the ribs was reduced.
- Activated muscle tonus does not change the submarining behavior.



Further Investigations

- Next steps are:
 - Finishing positioning tool for human FE-models with additional focus on unusual seating positions
 - Study of comfort seating positions for extended passive safety
 - Study of 5 percentile human model regarding submarining behavior compared to the hybrid dummy
 - Study of seat parameters regarding submarining



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Thank you for your attention!

