# Effects of geometric variations of anterior iliac wings on submarining risk in reclined seating

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## I. INTRODUCTION

In frontal crashes, submarining is a significant risk that can lead to severe pelvic and abdominal injuries. Previous studies have already highlighted that the likelihood of submarining is influenced by the shape or angle of occupant pelvic bone geometry [1]. Instead of more global geometrical changes of the pelvic bone, in this study only the local anterior iliac crest was modified for the THUMS v4.1 finite element (FE) human body model (HBM), based on post-mortem volunteer image scan data. The question should be answered if this variation affects a submarining risk. A better understanding of the relationship between iliac wings shape and submarining risk is necessary to improve occupant protection and design safer vehicle restraint systems.

## II. METHODS

The study utilised three existing post-mortem CT-scans of male and female subjects out of a dataset from the Institute of Legal Medicine of LMU University Munich and focused on the anterior iliac wings region, from which the most divergent geometries were selected. Two distinct categories of geometries were identified based on their shape: one steeper, vertically oriented, with more pronounced ASIS; and one flatter, horizontally oriented, with less pronounced ASIS (see Fig. 1). These geometries served as target geometries to which the pelvic geometry of THUMS v4.1 was adapted via morphing.

To accurately adjust the pelvic geometry based on the CT data, it was necessary to define landmarks in both the image data and the FE model. Regular landmarks which represent the fundamental outer shape of the anterior iliac wings were selected and used for the adaptation of pelvic shapes. Semi-landmarks were set between those regular landmarks to get a sufficiently representative shape of the anterior iliac wings. Three extreme geometries from the dataset, in addition to the basis geometry of THUMS v4.1, were selected for this study (Fig. 1).

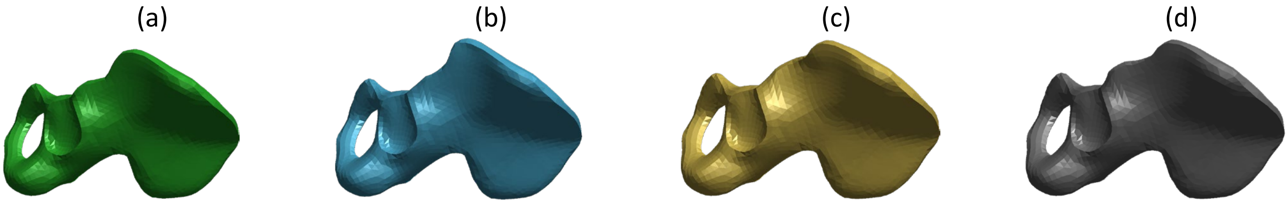


Fig. 1. Comparison of four considered geometries of anterior iliac wings, in THUMS v4.1. Geometry (a) represents the unmodified pelvis, (b)–(d) are morphed geometries based on three different individuals from the LMU database.

The preprocessor ANSA (v22.1.1, BETA CAE Systems) and its direct morphing toolbox were used to sequentially morph the landmarks along the basis pelvic anterior iliac wings shape of THUMS v4.1 to the target landmarks of all three individuals, also including the directly linked soft tissue of the pelvic bone. The differences between the four geometries were documented with the aid of various geometric parameter values, accordingly to [2].

Fig. 2. Setup from Uriot *et al.* [5-6] with THUMS v4.1.

TABLE I
VARYING INPUT PARAMETER VALUES AND THEIR RANGES IN URIOT *ET AL*. SETUP

| | |
|---|---|
| Acceleration pulse scaling factor | 50–150% |
| Friction coefficient belt – occupant | 0-1 |
| Friction coefficient seat – occupant | 0-1 |
| Time to fire of all three pretensioners | 5–120 ms |

Subsequently, all four models were integrated into the setup of Uriot *et al.* [3] and positioned in a reclined seating posture, following [4] and illustrated in Fig. 2. Finally, a parameter study was conducted, where several input variables were varied 50 times using a Sobol sampling method [5] (see Table I). As a result, each of the 50 simulation runs had a different input parameter configuration. The same 50 simulation runs were performed for each of the four geometries. All simulations were executed using LS-Dyna R9.3_706 MPP with a simulation time of 150 ms. The aim of this parameter study was to determine whether some geometries exhibit submarining while others do not under the same boundary conditions.

## III. INITIAL FINDINGS

In some of the 50 simulation runs, the four geometries show different behaviour with respect to submarining occurrence, which is illustrated in Fig. 3. The two flatter geometries, (c) and (d), show more submarining cases in total then the two steeper geometries, (a) and (b) (Fig. 4).

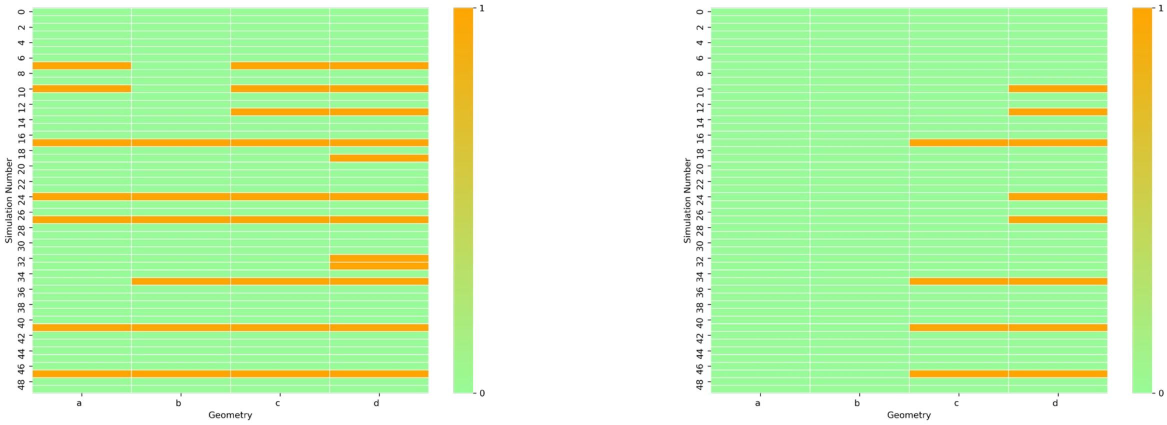


Fig. 3. Submarining occurrence for all four geometries in all 50 simulation runs. Orange highlighted columns indicate submarining cases, light green non-submarining cases (left plot = left body side, right plot = right body side).

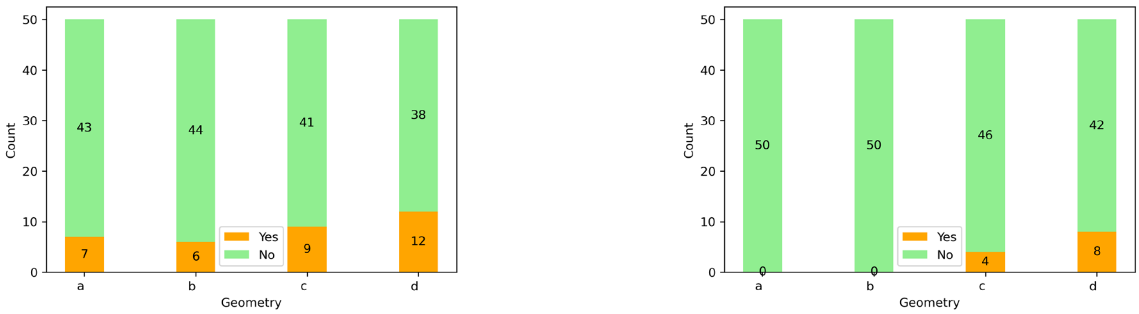


Fig. 4. Quantity of total submarining cases per geometry, based on all 50 simulation runs (left = left body side, right = right body side).

## IV. DISCUSSION

This study highlights that even small local variations in the geometry of anterior iliac wings can affect submarining risk. Individuals with more vertically oriented wings or a deeper, more pronounced notch are less likely to submarine, as their pelvis is better able to resist forward motion (Fig. 4, geometries (a)–(b)). Conversely, those with flatter and more horizontally oriented anterior iliac wings are more prone to submarining and may suffer more severe injuries as a result (Fig. 4, geometries (c)–(d)). Such pelvis variance is currently barely considered in submarining risk investigations. These results may have implications for future restraint system development. However, further studies are needed to confirm these findings, especially because this study only investigated the effect of geometrical modifications of the bony part around ASIS, and other factors, such as soft tissue thickness or material properties, may also play a role. Additional limitations of this study are the rigid seat environment, as well as the possible confounding nature of the environment parameters.

## V. REFERENCES

[1] Izumiyama, *et al.*, IRCOBI, 2020.
[2] Muehlbauer, *et al.*, IRCOBI, 2020.
[3] Uriot, *et al.*, *Stapp J,* 2015.
[4] Gepner, *et al.*, IRCOBI, 2019.
[5] Blatman, *et al.*, *Mechanics&Industry,* 2007.