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Effect of Contact Separation on the Abdominal Response to Impact of a Human Body Model

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ABSTRACT – In the GHBMC Detailed Human Body Models, sliding anatomical relationships between abdominal organs are modelled using sliding surface-to-surface contacts. As such contacts may open (i.e. separate) unrealistically in tension, their *in situ* behavior was analyzed in various setups. Surface separation was observed in abdominal and thoracic areas. It was most prominent in tension on the non-struck side of side impact sleds. Surface-to-surface distances also decreased significantly in compression. Adding tiebreak sliding contacts prevented separation and helped maintain these distances throughout the simulation. Resulting changes on the external response and liver strain energy density were limited but there was some improvement of the internal liver kinematics. Overall, such contact may help improve the realism of Human Body Models internal response.

INTRODUCTION

Detailed Human Body Models such as the GHBMC 50th percentile male (M50) describe the main abdominal and thoracic organs. For the abdomen, anatomical relationships between organs are simulated using continuous meshes, tied or sliding contacts in Ls-Dyna (R7.1.3, LSTC, Livermore, CA). For sliding, the automatic surface-to-surface formulation is used. It allows surfaces to separate in tension, which would be unrealistic in the absence of free air in the trunk. It also only transmits compressive forces after a surface distance is reached (contact thickness). Recently, the trajectories of a liver landmark were compared to *in situ* PMHS tests (Le Ruyet et al., 2016). While the simulations captured some of the experimental trends, peak displacements were overestimated and a final rebound seen in the tests was not predicted. Contact modelling was hypothesized as one of the possible reasons for some of these discrepancies.

The objectives of this study were (1) to investigate contact opening (separation) and numerical options to prevent it, and (2) assess the effect on the external and internal response in various experimental setups.

METHODS

The one-way surface-to-surface tiebreak with sliding was selected based on simplified test cases. It transmits loads in tension and compression to maintain the node to surface distance while allowing sliding. It was introduced in the GHBMC M50 v4.5 by adding contacts in sliding areas between: (C1) abdominal organs and surrounding fat, (C2) abdominal organs and surrounding cavity, and (C3) thoracic organs and surrounding cavity. Continuous null shell meshes were used to define the contact and limit the risk of locking at the surface borders. Contact thicknesses were set at 1, 10 and 10 mm for C1, C2 and C3, respectively.

For the assessment, baseline runs were compared with simulations with the new contacts. The M50 was first subjected to seven loading conditions used in Beillas and Berthet (2017, 2018). Surface-to-surface separation distances in C2 and C3 were computed using Ls-Prepost (LSTC). Then, similarly to Le Ruyet et al. (2016), the M50 was scaled to the dimensions of the 5 PMHS tested. It was then loaded in three of the impact locations (15 simulations). Liver landmark kinematics were analyzed as in the original study.

RESULTS

Initial separation distances between C2 and C3 surfaces were variable and mostly smaller than 10 mm (Figure 1 left). For the baseline, these distances decreased with compressive loading in some areas. Conversely, separation distances increased in others (opening). This contrasted response was especially prominent in side impact sleds (Figure 1 center). With the new contacts, most nodes in C2 and C3 were tied at initialization (C2: 16469 out of 18294, C3: 32739 out of 38549) as they were in the contact thickness. The separation distance was better conserved throughout the simulation (Figure 1 right vs. middle). The new contacts had limited effect on the external response (e.g. Figure 2 for one of the cases with the largest effect). In all cases, peak differences were lower than 10% for force, penetration and liver strain energy density.

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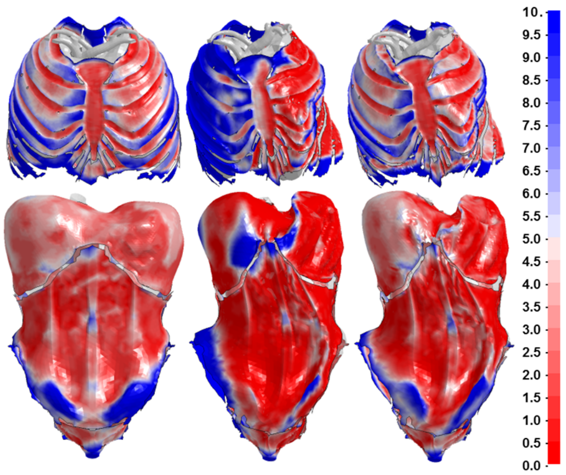

Figure 1: Separation distance (mm) for thorax (C3, top) and abdominal (C2, bottom) contact surfaces in Cavanaugh et al (1996) 7m/s side impact sled. At 0 ms (left) and 30 ms (center: baseline. right: new contacts).

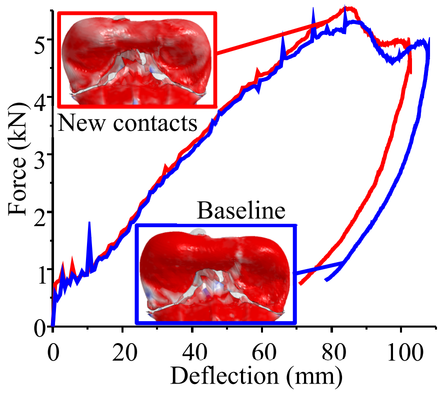

Figure 2: response in the Hardy et al (2001) upper abdomen bar impact. The lower peak penetration with the new contacts is consistent with a better conservation of the surface distances in C2.

For liver kinematics, the new contacts also had a limited effect on the liver trajectory shapes but improved slightly the trajectory metrics: average relative errors were reduced by 9% (0.5mm), 33% (2.3mm) and 4% (0.7 degree) for peak X displacement, peak Z displacement and initial angle, respectively ($p=0.01$). In simulations with the new contacts, an initial nodal motion of up to 2mm was observed locally on the surfaces of some soft structures (e.g. vessels). This artefact, which was not in baseline runs, was attributed to the initialization of the new contacts.

DISCUSSION

The contact behavior visible in compression and tension of the baseline runs was consistent with the numerical formulation and contact thickness. It is likely to occur in all models using similar formulations and more consistent initial surface-to-surface distances may help with issues observed in compression. Additional contacts mitigating these effects had a limited impact on the external response but a reduction of the peak penetration could be detected in some cases. While preventing separation allows tensile stresses in some regions, the effect seemed limited on the liver strain energy density. Some improvements of the internal response were observed but discrepancies observed after the peak remained. Beyond the setups used in the current study, large openings could be more problematic in complex loading setups with several impacts or pre-crash events.

CONCLUSION

Preventing separation in sliding contacts between internal organs and improving organ coupling in compression had limited effect on the global response and possible organ injury metrics. However, it prevented opening artefacts and improved the internal kinematics. Such contacts should be considered in future models after further evaluation (e.g. initialization artifacts).

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