DEVELOPMENT OF A FINITE ELEMENT MODEL OF THE HUMAN BODY

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Abbreviations: THUMS = "Total HUman Model for Safety"

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ABSTRACT

A finite element human model, THUMS (Total HUman Model for Safety), was developed in order to study human body responses to impact loads. This paper briefly describes the structure of the human model, as well as some of the results of the simulations conducted to validate the model.

INTRODUCTION

A finite element model of the whole human body, THUMS (Total HUman Model for Safety), has been developed. The purpose of the THUMS model is for the LS-DYNA users to simulate responses of the human body sustaining impact loads. This paper briefly describes the structure of the human model, as well as some results of the simulations conducted to validate the model. Finally, we describe further development plan of the model.

OVERVIEW OF THE THUMS MODEL

The THUMS model represents 50 percentile American adult male in a seating posture. Figure 1 shows the whole structure of the THUMS model with some soft tissues removed to expose the skeletal structure. The model contains about sixty thousand nodes and eighty thousand elements that include thirty thousand solid elements, fifty thousand shell elements and three thousand bar or beam elements.

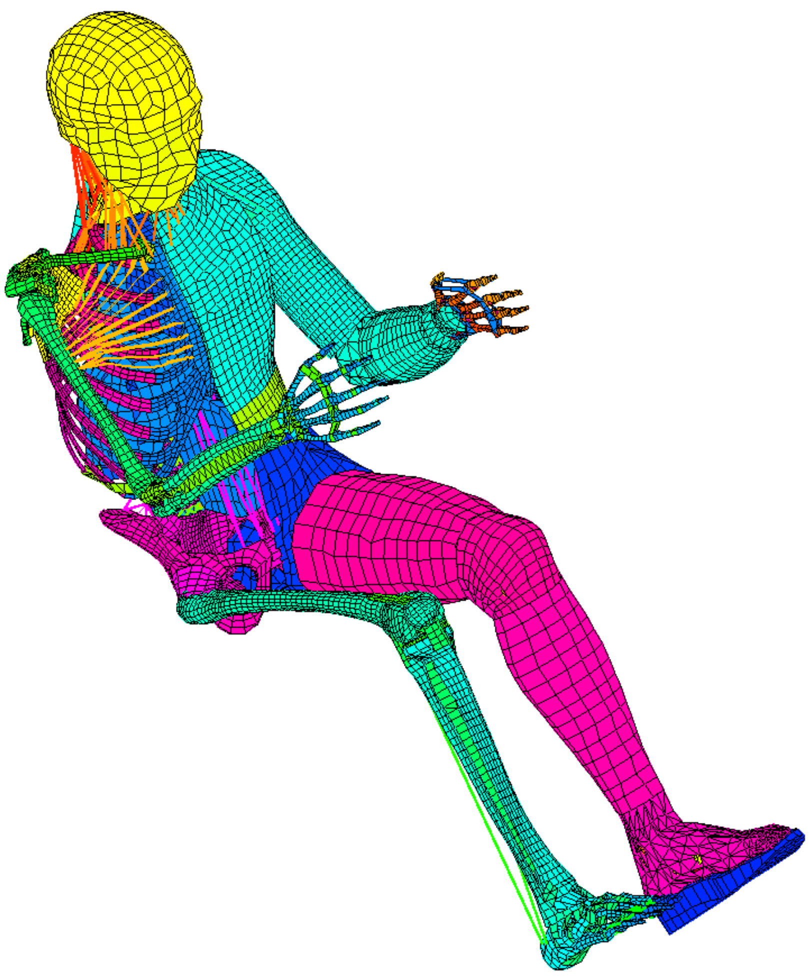

Figure 1. The THUMS Model with Some Soft Tissues Removed to Expose the Skeletal Structure

Whole skeletal structures are modeled in the THUMS model. Each bone consists of solid elements and shell elements; the solid elements represent the cancellous bone while the shell elements represent the cortical bone. In the joints of the THUMS model, ligaments that connect the bones are modeled by using shell elements or beam elements and sliding interfaces are defined on the contacting surfaces of these bones. In the thoracic cavity, the lung and heart are modeled as a single continuum body with solid elements. Abdominal organs are also modeled as continuum bodies. Skins and muscles that cover the bones are modeled with solid elements. The material properties of the tissues have been taken from Yamada (1970).

VALIDATION OF THE THUMS MODEL

Thoracic Frontal Impact Simulation

We have simulated the published cadaver impact tests conducted by Kroell et al. (1971 and 1974) to validate the response of the THUMS model to thoracic frontal impact. Figure 2 shows the set-up of the THUMS model and the pendulum. Though all the soft tissues are included in the simulation, the right half of the soft tissues is removed to expose the skeletal structure in the Figure 2. The arrow in the figure shows the direction of the pendulum's motion. In this simulation the mass and initial velocity of the pendulum are 23.4kg and 6.9m/s, respectively.

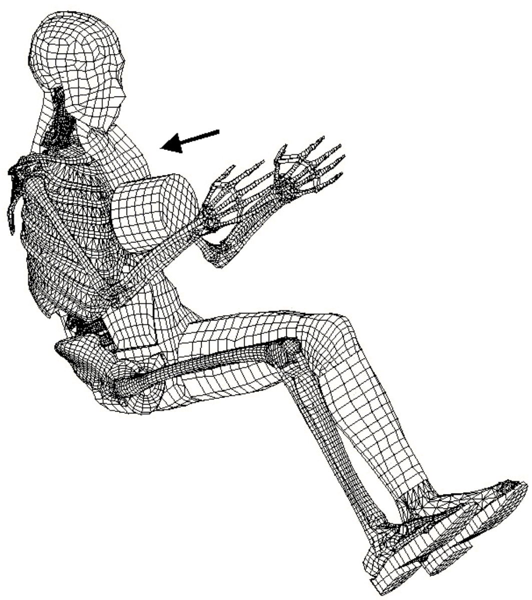

Figure 2. The Set-up of the Thoracic Frontal Impact Simulation

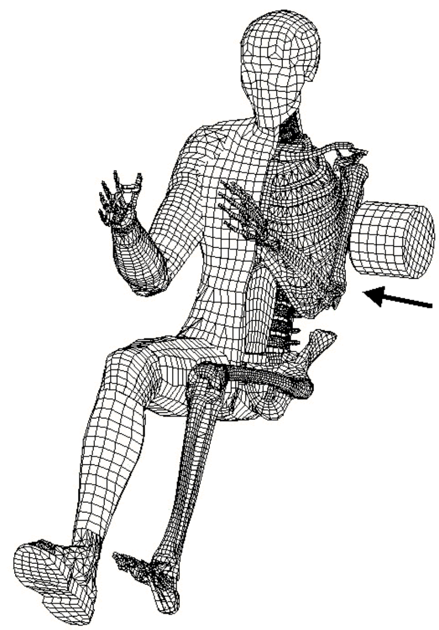

Figure 3. The Set-up of the Thoracic Side Impact Simulation

Thoracic Side Impact Simulation

The thoracic side impact simulation is discussed in this section. We have simulated the cadaver impact test conducted by Bouquet et al. (1994). Figure 3 shows the configuration of the THUMS model and the pendulum. In this simulation the mass and initial velocity of the pendulum are 23.4kg and 5.9m/s, respectively. We show the direction of the pendulum's motion by the arrow in the figure.

Pelvic Side Impact Simulation

In this section the pelvic side impact simulation is discussed. We have simulated the cadaver impact experiment reported by Viano (1989). Figure 4 shows the set-up of the THUMS model and the pendulum. In this simulation the mass and initial velocity of the pendulum are 23.4kg and 9.5m/s, respectively. The arrow in the figure indicates the direction of the pendulum’s motion.

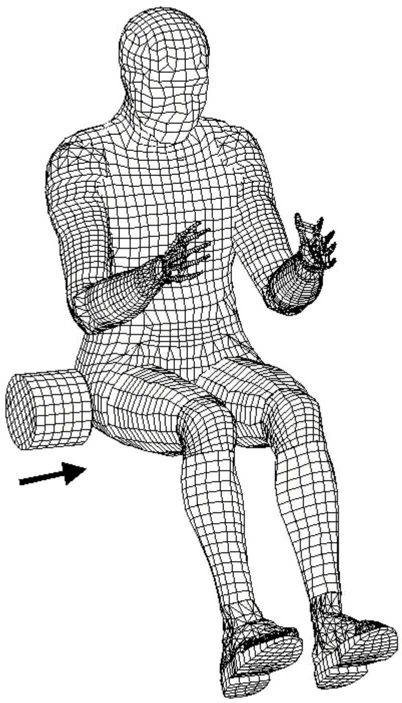

Figure 4. The Set-up of the Pelvic Side Impact Simulation

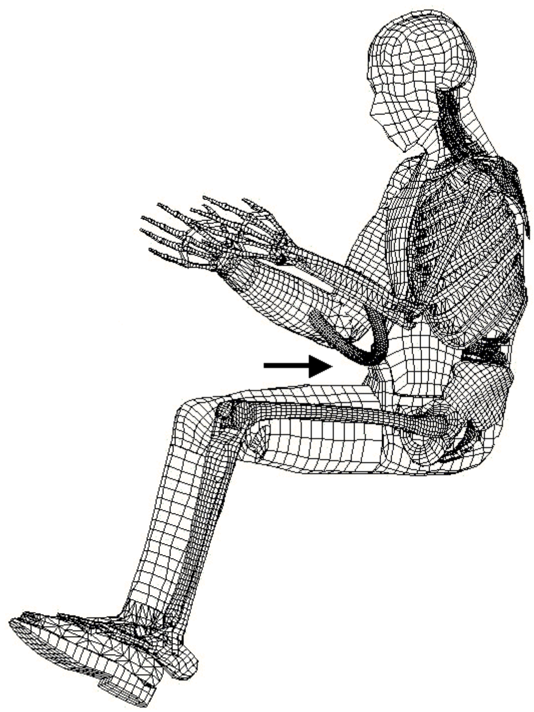

Figure 5. The Set-up of the Abdominal Frontal Impact Simulation

Abdominal Frontal Impact Simulation

In this section the abdominal frontal impact simulation is described. We simulated the cadaver impact tests conducted by Nusholtz et al. (1988). Figure 5 shows the THUMS model and the pendulum that simulates a lower half of a steering wheel. In this simulation the mass and initial velocity of the pendulum are 18kg and 10m/s, respectively. The arrow in the figure indicates the direction of the pendulum’s motion.

RESULTS AND DISCUSSION

Thoracic Frontal Impact Simulation

Figure 6 shows the relation between the chest deflection in the antero-posterior direction and the impact force sustained by the chest. The solid line shows the simulation result, while the dashed lines show the upper and lower limits of the corridor obtained by Kroell et al. (1971 and 1974). The simulation result shows a good agreement with the experimental data. Figure 7 shows the deformation of the model at 0, 20, 40, and 60msec. The right half of the soft tissues are not shown in this figure to expose the skeletal structure.

Although the overall force-deflection response of the model shows a good agreement with the experimental corridor, the unloading path of the model response deviates from the corridor. Therefore, we may add more energy-absorbing capabilities to the materials of the thoracic tissues so that the unloading path of the model response can be more accurate.

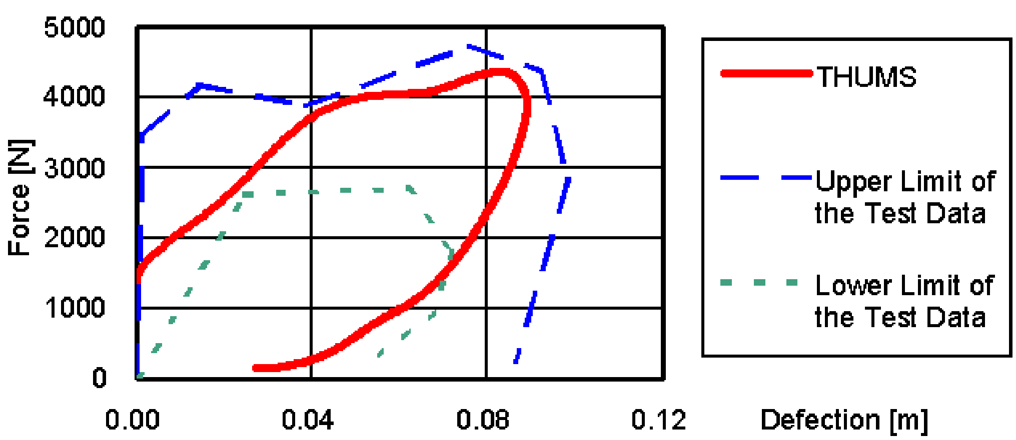

Figure 6. Force-deflection curve obtained from the thoracic frontal impact simulation and the cadaver test conducted by Kroell et al (1971, 1974)

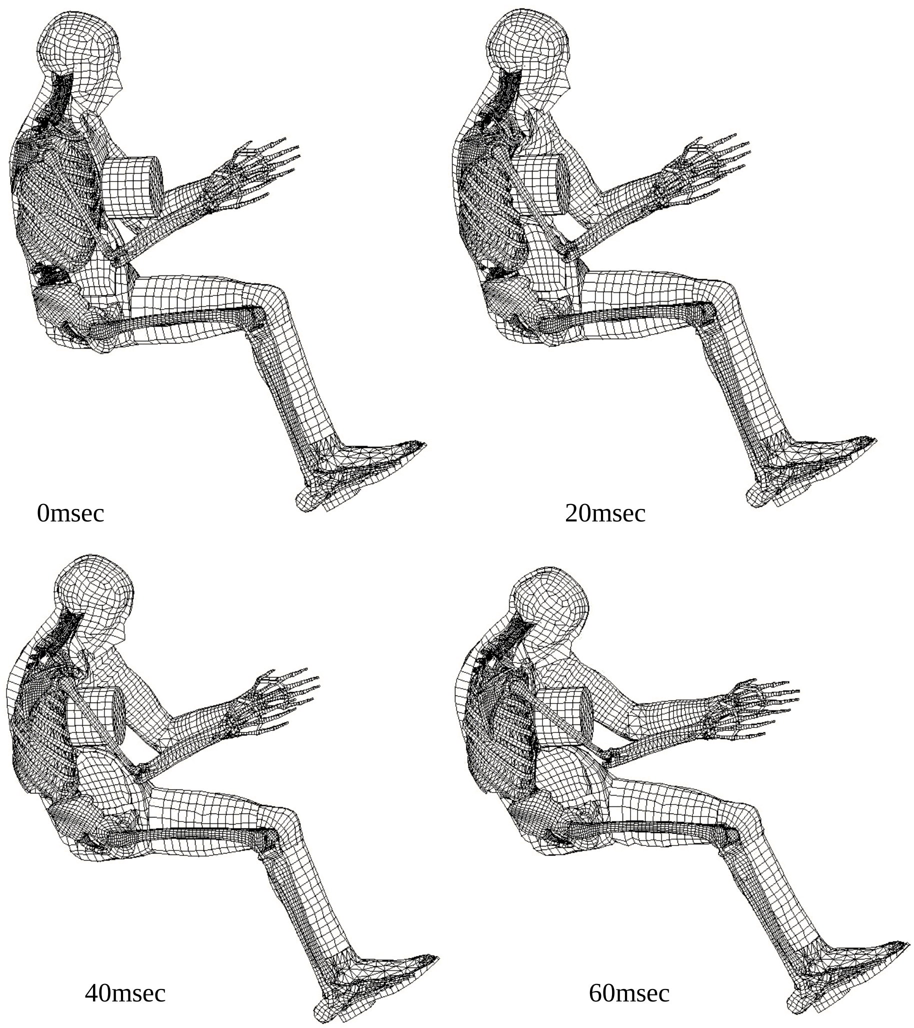

Figure 7. Deformation of the body obtained from the thoracic frontal impact

Thoracic Side Impact Simulation

Figure 8 shows the relation between the chest deflection in the lateral direction and the impact force sustained by the chest. The solid line represents the result from the simulation, while the dashed lines show the upper and lower limits of the corridor reported by Bouquet et al. (1994). The model response shows a good accordance with the experimental data. Fig. 9 shows the deformation of the model at 0, 20, 40, and 60msec. The soft tissues are not shown in this figure in order for the readers to see the motion of the skeletal structure.

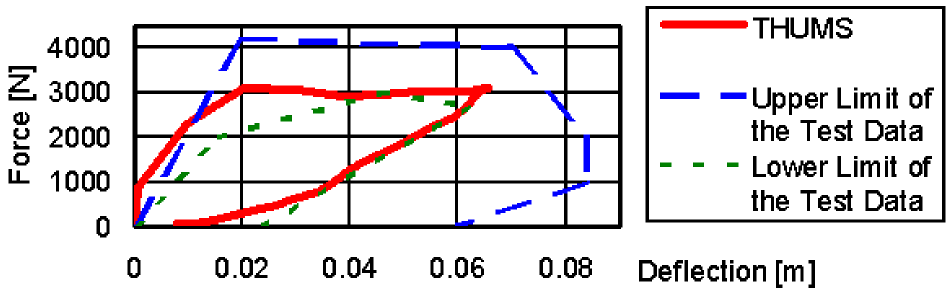

Figure 8. Force-deflection curve obtained from the thoracic side impact simulation and the cadaver test reported by Bouquet et al (1994)

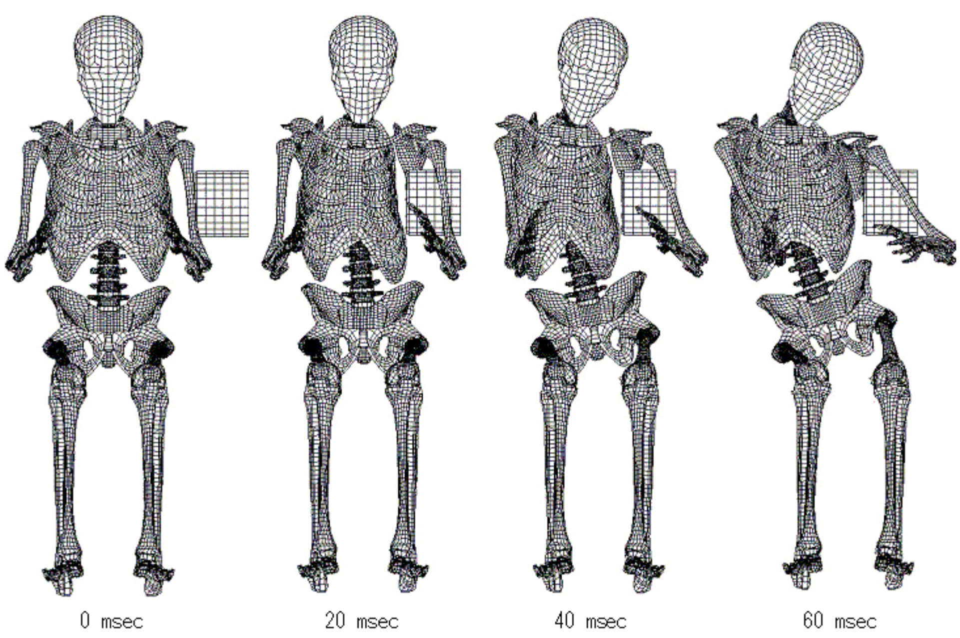

Figure 9. Deformation of the body obtained from the thoracic side impact simulation

Pelvic Side Impact Simulation

Figure 10 shows the relation between the pelvic deflection in the lateral direction and the impact force sustained by the pelvis. The solid line represents the result from the simulation, and the dashed lines show the upper and lower limits of the corridor reported by Viano (1989). Except the initial stage of the contact, the force-deflection response of the model shows a good agreement with that of experimental data. Figure 11 shows the deformation of the model at 0, 20, and 40msec. The soft tissues are not shown in the figure to expose the skeletal structure.

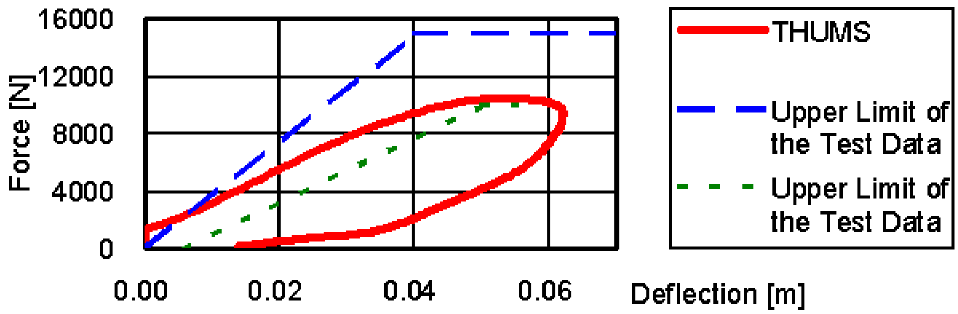

Figure 10. Force-deflection curve obtained from the pelvic side impact simulation and the cadaver test reported by Viano (1989)

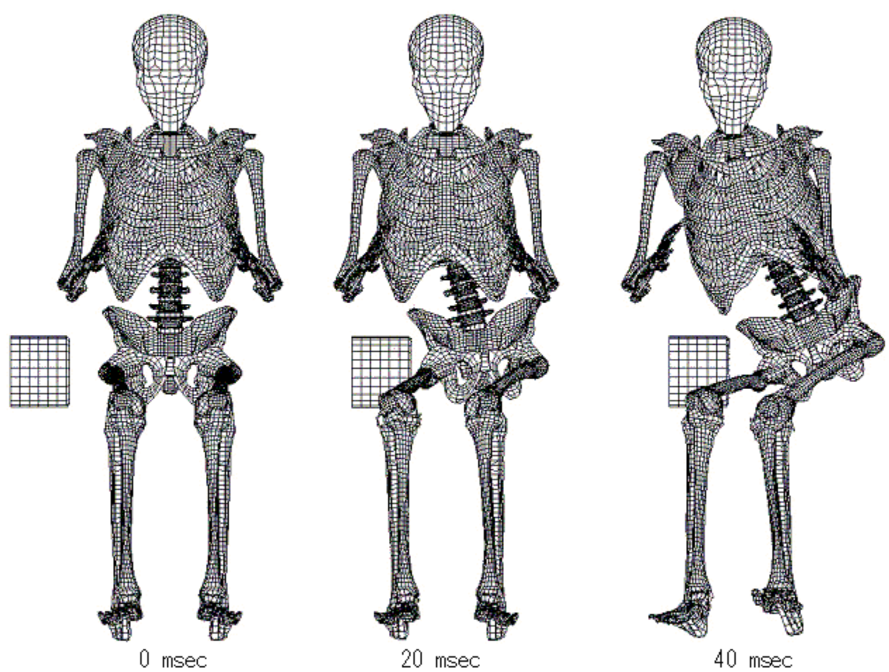

Figure 11. Deformation of the body obtained from the pelvic side impact simulation

Abdominal Frontal Impact Simulation

Figure 12 shows the relation between the abdominal deflection in the antero-posterior direction and the impact force sustained by the abdomen. The solid line without markers represents the simulation result, while the solid lines with markers show the experimental results reported by Nusholtz et al. (1988). The force-deflection curve obtained from the simulation is very similar to those obtained from the experimental study. Figure 13 shows the deformation of the model at 0, 20, 40, and 60msec. Some soft tissues of the model are not shown in the figure to show the motion of the skeletal structure.

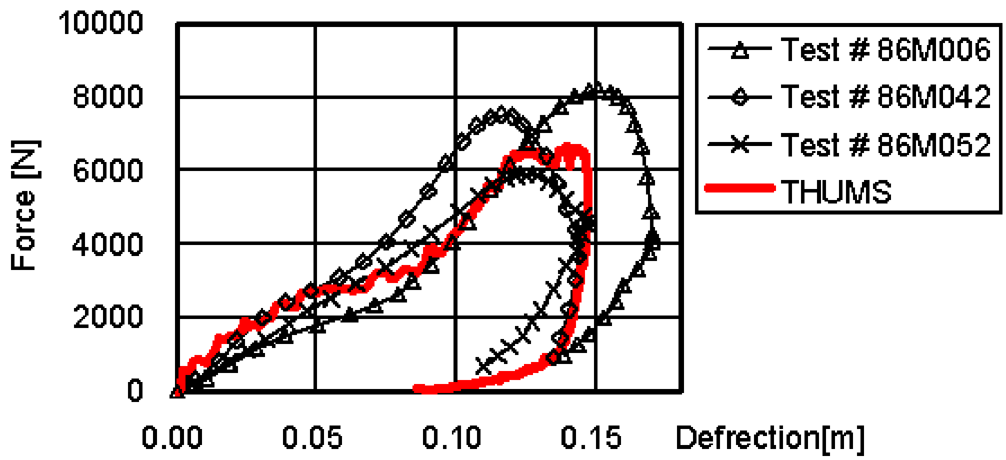

Figure 12. Force-deflection curves obtained from the abdominal frontal impact simulation and the cadaver test conducted by Nusholtz et al (1998)

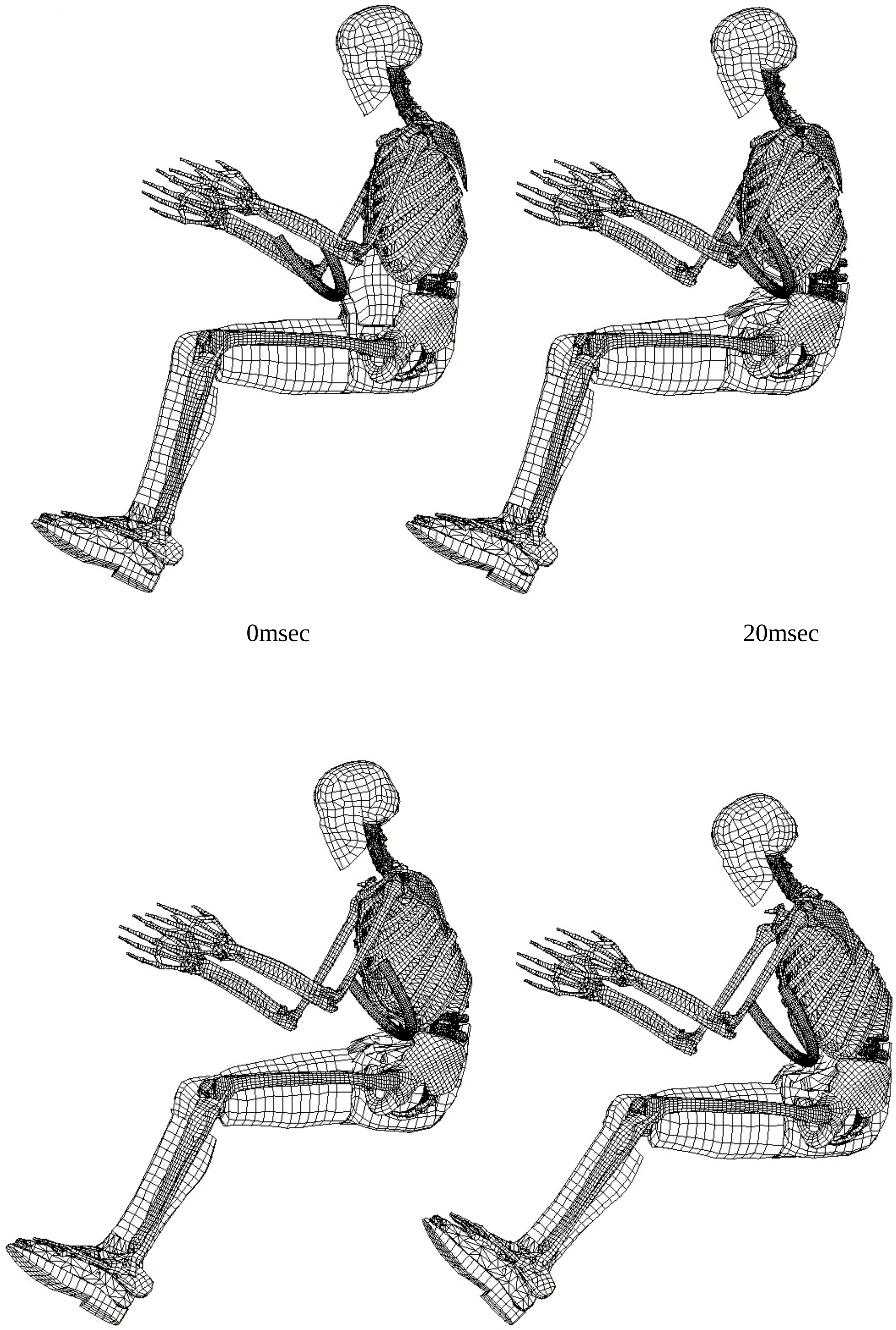

Figure 13. Deformation of the body obtained from the abdominal frontal impact simulation

FURTHER DEVELOPMENT OF THE THUMS MODEL

Although we have modeled whole human skeletal structures, internal organs are not modeled individually; as we have described above, several internal organs are fused to form continuum bodies. Homogeneous material properties are assigned for each of the continuum body while the internal organs in the actual human body have different material properties. Moreover, even within individual organ, the material properties are not homogeneous. Therefore, the model cannot be used to predict the mechanical response of the internal organs accurately.

In order for the users to investigate on the mechanical response of the internal organs in the human body sustaining impact loads, we will replace the simplified internal organ models with those that have more realistic representation. The future version of the model will include individual heart, lung, stomach, intestine, liver, spleen, and kidney model. In addition, we will develop a pedestrian model and small female model.

When the human body is exposed to an impact load, soft tissues of the internal organs can sustain large strain and strain rate. In general, soft tissues exhibit nonlinear stress-strain relationships under a large strain. Moreover, strain rate dependency in the material properties of these soft tissues cannot be neglected in some cases. Therefore, nonlinear viscoelastic material models are necessary in order to represent the behavior of the soft tissues that sustain large strain and strain rates. In addition, anisotropy due to the fibrous materials in the connective tissues such as ligaments and tendons cannot be neglected. In our current model, linear isotropic constitutive equations are used to model the soft tissues. We will try the non-linear anisotropic viscoelastic material model that has been implemented in LS-DYNA version 960 (Weiss et al., 1996) so that the users can simulate the response of the soft tissues more accurately.

CONCLUSION

In order for the users of LS-DYNA to investigate on the response of the human body under impact loading conditions, we have developed the THUMS model, a whole human body model for LS-DYNA.

Several published cadaver impact tests (Kroell et al., 1971, Kroell et al., 1974, Bouquet et al., 1994, Viano, 1989, Nusholtz et al., 1998) were simulated and the model was verified by comparing the force-deflection responses of the model and those obtained from the cadaver tests. For each of the simulations, the model response to the impact loads showed a good agreement with the cadaver response.

In the future we will replace the simplified internal organ models with more sophisticated ones. In addition, we will develop a pedestrian model and a small female model.

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