A Survey on the Biofidelity of the Knee Bending Angle of the TRL Lower Leg Impactor

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ABSTRACT

This paper describes the biofidelity of the TRL lower leg impactor (here after referred to as "The Impactor"). The knee-bending angle biofidelity of The Impactor is compared with the THUMS (Total HUman Model for Safety) FEM human body model. Detailed sedan and SUV FEM models were generated and were correlated with test results. FEM results show The Impactor's knee-bending angles correlate well with test results.

When the tibia deflection of The Impactor is small, The Impactor has a larger knee-bending angle than the THUMS model in a finite element (FE) analysis of the pedestrian impacted by a sedan. When the tibia deflection of the THUMS is small, The Impactor has a similar knee-bending angle to the THUMS model in FE analysis of a pedestrian impacted by an SUV.

Movement of The Impactor coincides with the THUMS model in an FE analysis of the pedestrian impacted by a sedan until the medial collateral ligaments ruptured. Movement of The Impactor does not coincide with the THUMS model in FE analysis of a pedestrian impacted by an SUV with a bumper height 520 mm. If the bumper height of the SUV is less than 420 mm, movement of The Impactor is similar to that in the THUMS model.

Biofidelity of the knee-bending angle of The Impactor is not sufficient if compared with the THUMS model. Deflection of the tibia should be taken into account to improve biofidelity of The Impactor's knee-bending angle.

INTRODUCTION

Rupture of pedestrian knee ligaments are sometimes observed in car to pedestrian accidents. The Impactor is one tool to evaluate the rupture of these knee ligaments. The Impactor measures the knee-bending angle in order to estimate the rupture of knee ligaments. Biofidelity of the knee-bending angle is crucial in order for The Impactor to precisely evaluate the possibility of knee ligament rupture. A comparison of the knee-bending angle of The Impactor with the knee-bending angle of a human would be effective in realizing the difference in behavior between The Impactor and a human leg. An FE model of the lower leg impactor and an FE human body model can be utilized to compare these knee-bending angles.

FE MODELS

Four FE models were generated to evaluate the knee-bending angle of a pedestrian as follows:
Case 1: Sedan and The Impactor (Figure 1),
Case 2: Sedan and THUMS (Figure 2),
Case 3: SUV and The Impactor (Figure 3),
Case 4: SUV and THUMS (Figure 4).
The author developed The Impactor FE model. The human FE model is the Total Human Model for Safety developed by the Toyota Central Research and Development Laboratory and Toyota Motor Corporation (Figure 5). THUMS is the same size as an AM50 percentile size.

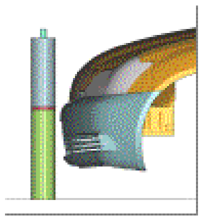


Figure 1. Sedan and The Impactor

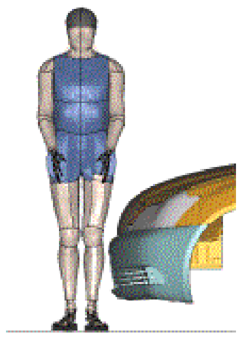


Figure 2. Sedan and THUMS

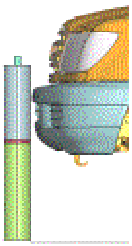


Figure 3. SUV and The Impactor

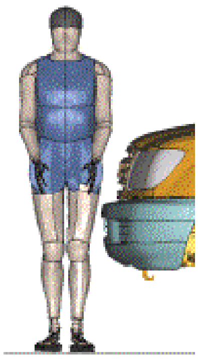


Figure 4. SUV and THUMS

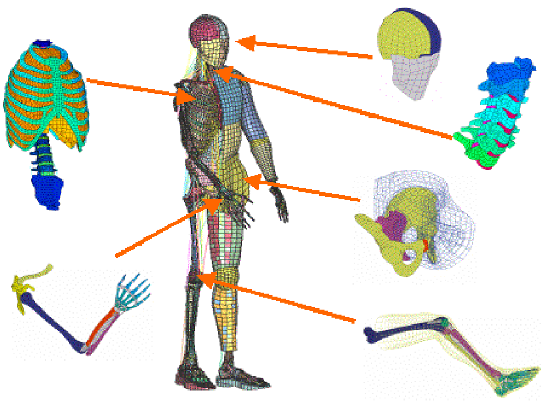


Figure 5. THUMS

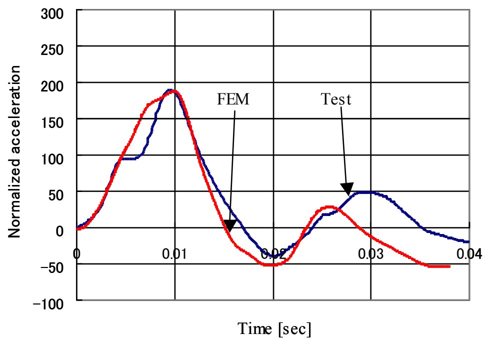


Figure 6. Comparison of acceleration in case 1

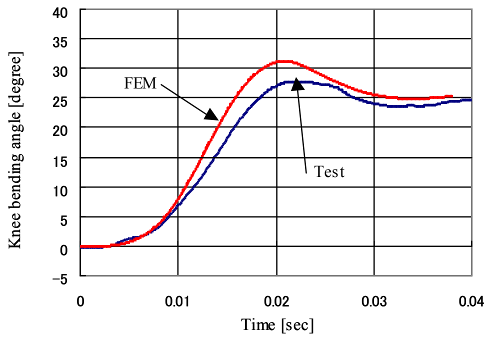


Figure 7. Comparison of knee-bending angle in case 1

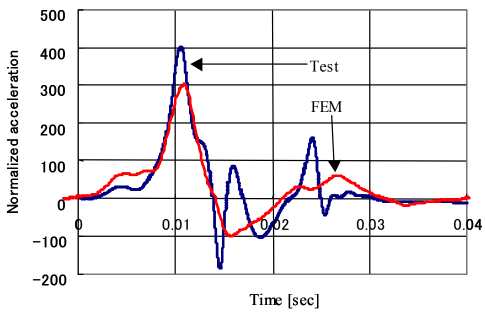


Figure 8. Comparison of acceleration in case 3

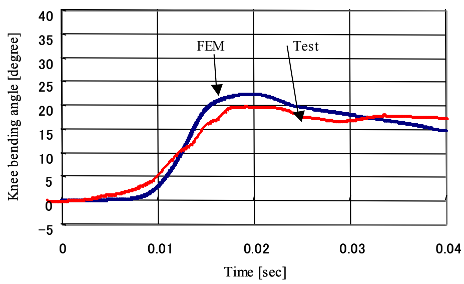


Figure 9. Comparison of knee-bending angle in case 3

MODEL VALIDATION

The THUMS pedestrian model was validated with test results with post mortem human subjects [1,2].

Two tests were conducted in order to evaluate the accuracy of the knee-bending angle of case 1 and 3. The test conditions are similar to the EuroNCAP procedure[3]. Both validations show good correlations of acceleration and knee-bending angle with the tests (Figure 6,7,8,9).

KNEE-BENDING ANGLE

Knee-bending angles calculated for case 1 and case 2 are shown in Figure. 10. The knee-bending angle of The Impactor coincides with THUMS from 0 sec to 0.01 sec. The knee-bending angle of The Impactor is greater than THUMS from 0.01 sec to 0.033 sec.

The MCL of THUMS model was ruptured at 0.028 sec, while the maximum knee-bending angle of The Impactor occurs at 0.20 sec.

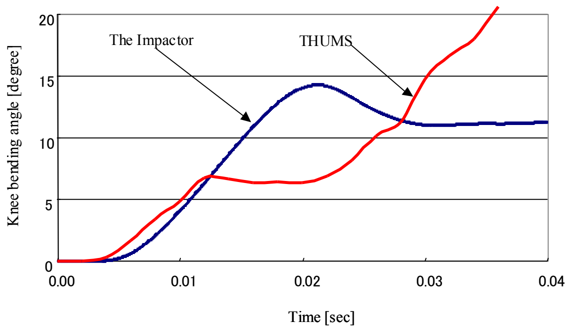


Figure 10. Knee-bending angles of THUMS model and The Impactor.

The knee-bending angle calculated for case 3 and case 4 are shown in Figure 11. The knee-bending angle of The Impactor coincides with THUMS from 0 sec to 0.02 sec.

The MCL of the THUMS model was ruptured at 0.012 sec, while the knee-bending angle of The Impactor increased to 15 degrees at 0.013 sec.

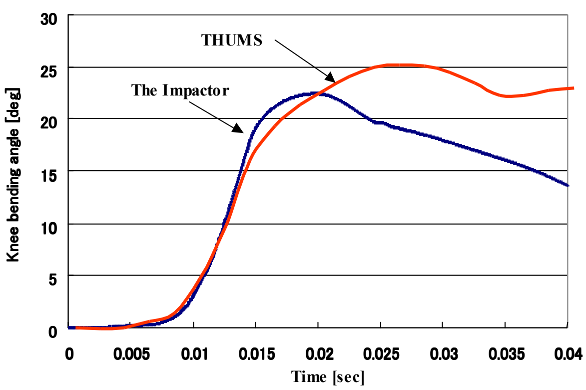


Figure 11. Knee-bending angle in cases 3 and 4

DISCUSSION

SEDAN VS. THUMS AND IMPACTOR

THUMS and The Impactor movements observed relative to fixed coordinates on the vehicle in cases 1 and 2 are shown in Figure 12.

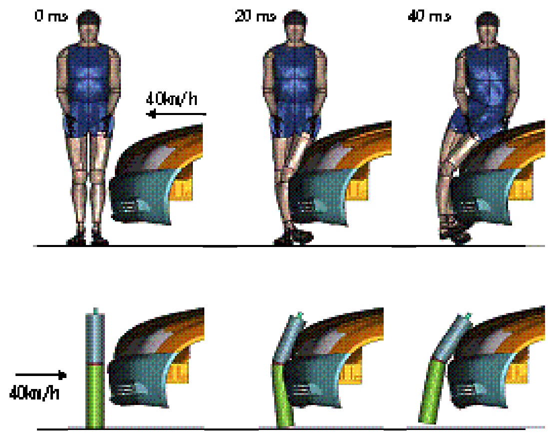


Figure 12. Movements of THUMS and The Impactor vs. Sedan

Movements of The Impactor are similar to THUMS at 0.02 sec, but the bumper fascia bends the tibia of THUMS. The tibia of The Impactor is already rebounding from the bumper fascia while THUMS is still contacting the bumper fascia at 0.04 sec.

The tibia bending-angle and knee-bending angle of THUMS are shown in Figures 13 and 14. The knee-bending angle difference between THUMS and The Impactor increases as the THUMBS tibia bending-angle increases. These Figures indicate the tibia-bending deflection should be engaged in evaluating the knee-bending angle of the pedestrian.

The main reasons that The Impactor has a smaller tibia-bending angle than THUMS are as follows:

- THUMS has a fibula and a tibia, which are the same as a human leg, while The Impactor has one bone structure representing both the fibula and the tibia (Figure 15).
- The THUMS tibia has similar bending stiffness to that of post mortem human subject tests, while The Impactor has a much stiffer bending stiffness than post mortem human subject tests (Figure 16).

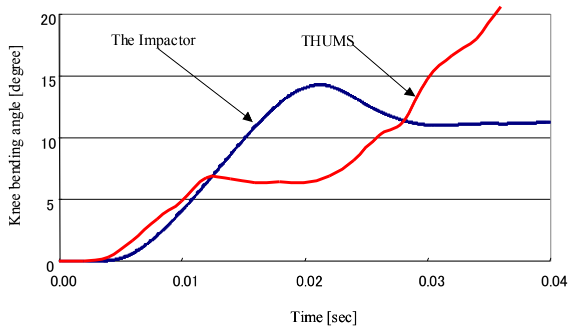


Figure 13. Knee-bending angle of THUMS and The Impactor in cases 1 and 2

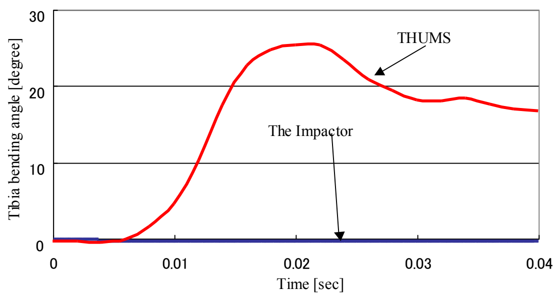
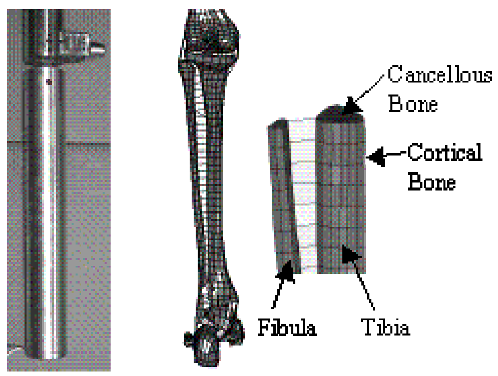


Figure 14. Tibia-bending angle of THUMS in case 2



Impactor THUMS

Figure 15. Comparison of fibula and tibia

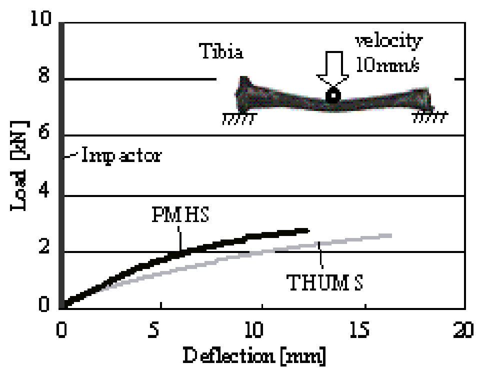


Figure 16. Force displacement relationship of tibia resulting from a 3-points bending test [1,2]

SUV VS. THUMS AND IMPACTOR

THUMS and The Impactor movements observed from fixed coordinates on the vehicle in cases 3 and 4 are shown in Figure 17. The Impactor movements are similar to THUMS at 0.02 sec. The THUMS tibia did not bend because the tibia does not come in contact with the bumper fascia. The Impactor's femur is already rebounding from the bumper fascia while the THUMS femur is still contacting the bumper fascia at 0.04 sec.

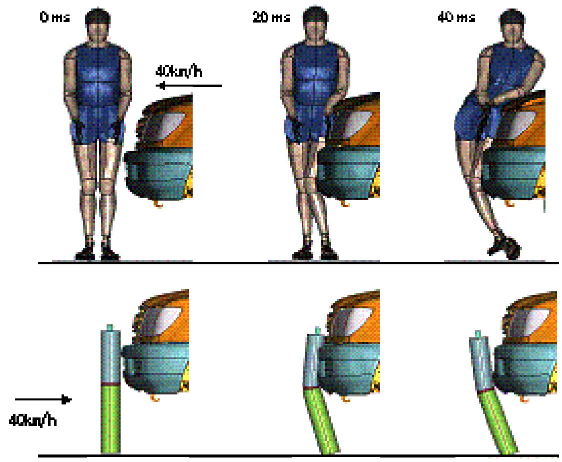


Figure 17. Movements of THUMS and The Impactor vs. SUV

The main reasons for The Impactor's femur rebounding at 0.04 sec are assumed as follows:

- THUMS has a similar femur bending stiffness to post mortem human subject tests, while The Impactor has much stiffer bending stiffness compared to post mortem human subject tests (Figure 18).
- THUMS has a knee structure similar to a human's knee. The knee-bending moment of THUMS is generated by elongation of ligaments, while the knee-bending moment ofThe Impactor is generated by plastic bending of a single steal plate (Figure 19). The knee-bending moment of THUMS is similar to post mortem human subject tests, while the knee bending moment of The Impactor is stiffer than post mortem human subject tests (Figure 20).

The author estimates that excessive bending stiffness of The Impactor's femur and knee-bending moment may affect rebounding of The Impactor's femur at 0.04sec. Also, the author estimates that bumper height may affect the rebounding of The Impactor's femur at 0.04sec.

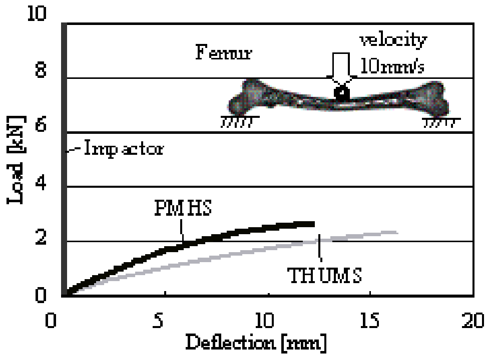


Figure 18. Force displacement relationship of femur 3-points bending tests [1,2]

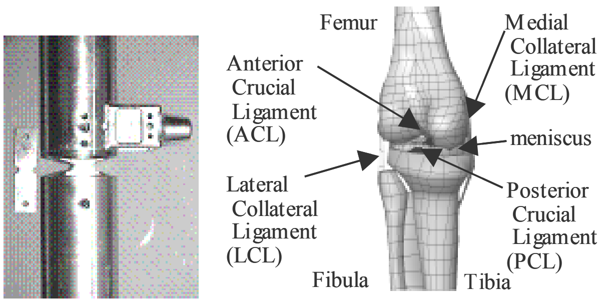


Figure 19. Comparison of knee structure

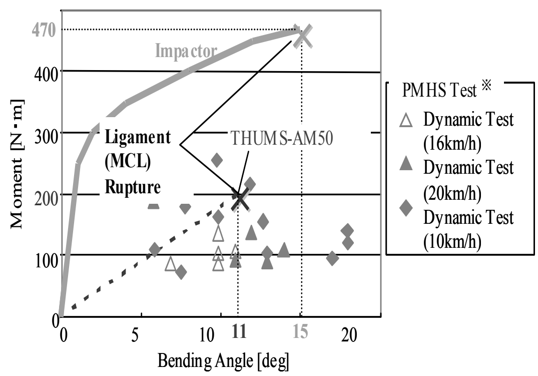


Figure 20. Moment bending angle relationship of knee[4,5,6]

BUMPER HEIGHT EFFECT

Lower bumper height (LBH) is defined as indicated in Figure . 21. LBH of the FE model for cases 3 and 4 is 520 mm. LBH of the FE model for case 3 was reduced to 420 mm, 320 mm and 220 mm.

The Impactor movements are shown in Figure 22. When the LBH is reduced to 420 mm, 320 mm and 220 mm, The Impactor's femur does not rebound at 0.04 sec. The LBH of 520 mm is too high to avoid rebounding of The Impactor's femur at 0.04[sec].

An LBH upper limit for testing should be applied to The Impactor, as long as The Impactor has no pelvic mass.

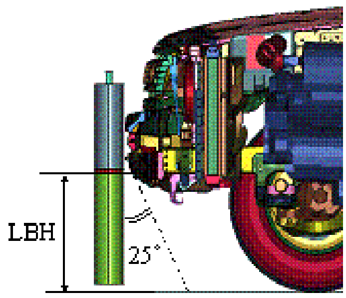


Figure 21. Definition of lower bumper height

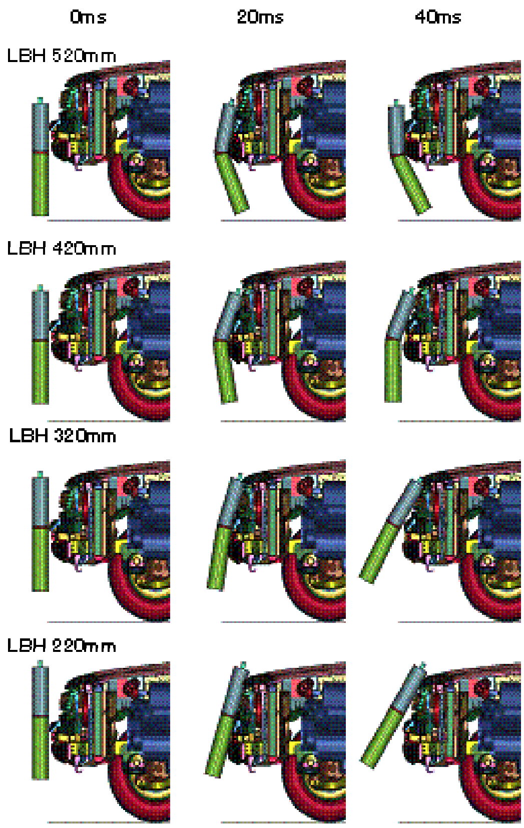


Figure 22. Impactor Movement at different LBHs

CONCLUSION

The knee-bending angle of the TRL lower leg impactor FE model was compared with the THUMS model.

The TRL lower leg impactor indicated more knee-bending angle than THUMS due to less bending deflection of the tibia in collisions with a sedan type vehicle. The tibia bending stiffness of the TRL lower leg impactor should be improved to better simulate similar knee-bending angle to that of THUMS.

The TRL lower leg impactor indicated a similar knee-bending angle to THUMS in a collision with an SUV type vehicle. However, rebounding of the TRL lower leg femur was observed. Lower bumper height for testing with the TRL lower leg impactor should be limited to avoid rebounding of the TRL lower leg impactor femur.

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