Research on Iliac Injury Risk Assessment of Reclined Occupant in Frontal Collision

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I. INTRODUCTION

This study presents a systematic analysis of the risk of reclined occupant pelvic iliac fractures in frontal collision. Previous post mortem human surrogate(PMHS) tests demonstrate that at a 50kph collision speed, the iliac injury severity can reach AIS 2-4, with higher AIS 2+ risks at larger recline angles[1-5]. The seatbelt lap belt force (F_{LB}) can partially characterize the pelvic loading state, but it cannot directly reflect the human biomechanical response, thus having limitations as assessment criteria. Existing anthropomorphic test devices (ATD), such as the THOR 50M and THOR-AV, although capable of measuring X-axial forces at the ASIS ($\mathrm{ASIS_{Fx}}$) measurement points, are limited by their single-axial measurement capabilities and cannot comprehensively characterize the complex loading of the pelvis. This study aims to evaluate the risk of iliac injury in reclined occupants by exploring multiple injury risk mapping methods between PMHS and ATD based on existing research [6-7], as well as processing dummy test data, to investigate the iliac load measurements of the THOR-AV at different iliac injury risk levels.

II. METHODS

This study utilizes three methods to derive injury risk curves for iliac AIS2+ injuries and determine thresholds for different injury probabilities, based on sensors' data from the THOR-AV.

Method 1: A linear mapping relationship between the THOR-AV's $ASIS_{Fx}$ and F_{LB} was established using 37 sets of data from reclined occupant sled tests in MPDB frontal impact test condition (Equation 1, Figure 1(a)). Combining the F_{LB} and $ASIS_{Fr}$ transformation model proposed by Richardson et al. [7] (Equation 2), the transfer function for the $ASIS_{Fx}$ and $ASIS_{Fr}$ for THOR-AV was derived (Equation 3). The $ASIS_{Fx}$ injury risk curve (Equation 4, Figure 1(b)) was obtained by integrating the transfer function into the AIS2+ injury risk function of $ASIS_{Fr}$ [6].

$$ASIS_{Fx} = 0.442 * F_{LB} - 0.189 \quad (1)$$

$$ASIS_{Fr} = 0.6083 * F_{LB} - 0.9062 \quad (2)$$

$$ASIS_{Fr} = 1.3763 * ASIS_{Fx} - 0.6461 \quad (3)$$

$$P_{ASIS_{Fx}} = 1 - \exp(-(\frac{1.3763*ASIS_{Fx}-0.6461}{\exp(8.637)})^{1.619}) \quad (4)$$

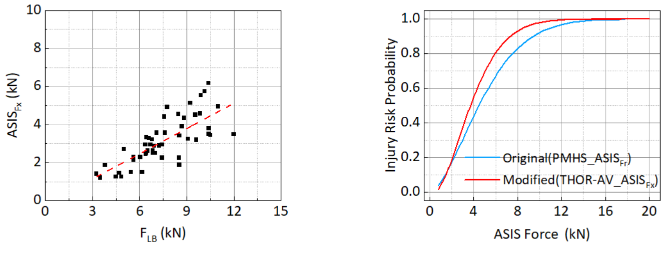

Figure 1. (a) Mapping relationship between $\mathrm{ASIS_{Fx}}$ and F_{LB} in THOR-AV tests in Method 1; (b) $\mathrm{ASIS_{Fx}}$ ASIS 2+ injury risk curve in Method 1.

Method 2: Based on 43 THOR-AV finite element simulations with production reclined seats in MPDB frontal impact test condition, which cover various seat types, recline angles (35°-65°), iliac wing loads were read out from these simulations. Based on the simulation results, another linear mapping relationship was established between $\mathrm{ASIS_{Fx}}$ and $\mathrm{ASIS_{Fr}}$ for THOR-AV (Equation 5, Figure 2(a)). Model constant term (0.0857) was statistically insignificant (p>0.05), thus it was removed from the model. This effort led to the $\mathrm{ASIS_{Fx}}$ injury risk curve (Equation 6, Figure 2(b)).

$$ASIS_{Fr} = 1.2911 * ASIS_{Fx} + 0.0857 \quad (5)$$

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$$P_{ASIS_{Fx}} = 1 - \exp(-(\frac{1.291*ASIS_{Fx}}{\exp(8.637)})^{1.619}) \quad (6)$$

Method 3: Wang et al. [8] developed an iliac AIS2+ injury risk curve for THOR-AV, using both physical tests and finite element simulations that matched to 62 PMHS tests (Figure 2(c)).

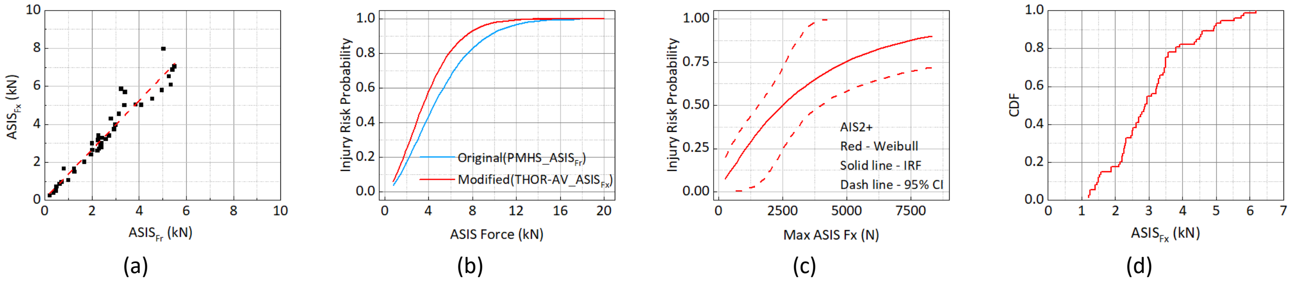

Figure 2. (a) Mapping relationship between $\mathrm{ASIS_{Fx}}$ and $\mathrm{ASIS_{Fr}}$ in THOR-AV simulations; (b) $\mathrm{ASIS_{Fx}}$ ASIS 2+ injury risk curve in Method 2; (c) $\mathrm{ASIS_{Fx}}$ AIS 2+ injury risk curve in Method 3; (d) Cumulative probability distribution of $\mathrm{ASIS_{Fx}}$.

Moreover, the cumulative distribution function (CDF) was used as an auxiliary evaluation for the biomechanical response of the iliac wing in dummy. 72 THOR-AV sled tests used different product reclined seats and recline angles (35°-65°) in MPDB frontal impact test condition were conducted by CAERI's intelligent cockpit safety working group. These THOR-AV iliac load data were sorted in ascending order to obtain the corresponding distribution ratio and construct the cumulative probability distribution curve of $\mathrm{ASIS_{Fx}}$ (Figure 2(d)).

III. INITIAL FINDINGS

Based on the injury risk functions derived from the above methods, the threshold values corresponding to AIS2+ injury probabilities of 25%, 50%, 75%, and 95% are statistically determined (Table 1).

Table 1. ILIAC INJURY THRESHOLDS FROM DIFFERENT METHODS

Methods	25%	50%	75%	95%
Method 1(kN)	2.37	3.74	5.48	8.54
Method 2(kN)	2.02	3.48	5.34	8.60
Method 3(kN)	1.02	2.46	4.92	10.63
Average(kN)	1.80	3.23	5.25	9.26

The results of above mapping methods on injury risk curves provide an evaluation point for the THOR-AV with respect to PMHS iliac wing injury risk in reclined occupant frontal collision scenarios. In this way, the THOR-AV $\mathrm{ASIS_{Fx}}$ measurement values can be used for reference under different iliac wing injury risks. Simultaneously, the constructed $\mathrm{ASIS_{Fx}}$ CDF reflected the actual performance of product seats in protecting reclined occupants. The results indicates that the corresponding thresholds at cumulative probabilities of 25%, 50%, 75%, and 95% are 2.26 kN, 2.89 kN, 3.50 kN, and 5.54 kN.

IV. DISCUSSION

In reclined occupant frontal collision scenarios, the iliac is one of the main injury regions. However, current iliac injury risk prediction methods face challenges. There is no standardized approach for measuring lap belt forces. It is essential to establish a standardized protocol for lap belt location and force measurement method. In the study of Method 2, it was found that the Y-axial force values at ASIS ($\mathrm{ASIS_{Fy}}$) in some simulation cases were comparable to $\mathrm{ASIS_{Fx}}$ in relation to $\mathrm{ASIS_{Fr}}$, with an average ratio of $\mathrm{ASIS_{Fy}}$ to $\mathrm{ASIS_{Fr}}$ across all cases being 67%. This indicates that the Y-direction load is significant, highlighting the necessity to investigate it further.

There are limitations in this study. The F_{LB} and $\mathrm{ASIS_{Fr}}$ transformation model proposed by Richardson is from THOR 50M simulations and contains data in normal sitting posture collision condition. Method 2 uses simulation data from various seat manufacturers, lacking a uniform benchmarking and physical test validation, limiting its reliability. Method 3 calibrates injury curves through PMHS tests, but the sample size for reclined seat is insufficient and no distinction is made between submarining and non-submarining cases. Despite the limitations, these injury risk curves, based on PMHS iliac injury data, are valuable for standardizing iliac force thresholds and improving reclined seat safety assessments.

V. REFERENCES

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