Evaluation of a Delta-Type Seat belt to Reduce Thoracic Loading in Frontal Impacts Using a Human Body Model.

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I. INTRODUCTION

The three-point seat belt has been identified as a significant contributor to thoracic injury in high-severity crash scenarios, due to its direct application of restraint force to the occupant's thorax [1–2]. Since the prevalence of thoracic injuries increases with age, the fact that societies are ageing underscores the need for seat belt systems capable of further reducing thoracic loading [2–3]. Previous studies have proposed four-point seat belt systems that restrain bilateral shoulders simultaneously. These systems impose no direct load on the sternum, thereby mitigating thoracic loading during impact. However, their efficacy remains to be conclusively established. In the present study, a delta-type four-point seat belt is compared with the conventional three-point seat belt using finite element (FE) analysis with a human body model.

II. METHODS

FE Model

The THUMS 50M model was seated in the front passenger seat in an upright seated posture under the deceleration pulse of a full-frontal impact of a small car (impact velocity: 50 km/h, maximum deceleration: 40 G). The restraint configurations (with an airbag) are shown in Figs. 1 and 2. The three-point seat belt had a conventional configuration for comparison. The delta-type seat belt was configured, such that two shoulder belts were routed from the upper seatback over the occupant’s shoulders and extended toward the left and right lateral abdominal regions, in combination with a lap belt. To reduce the spinal compressive loading identified in prior studies [2–3], a neck anchor was introduced at the upper seatback, through which the belts were routed from the retractor installed behind the upper seatback. The neck anchor was allowed to move horizontally (XY plane), and elongation elements were incorporated on the left and right sides of the neck anchor to generate a reaction force upon displacement.

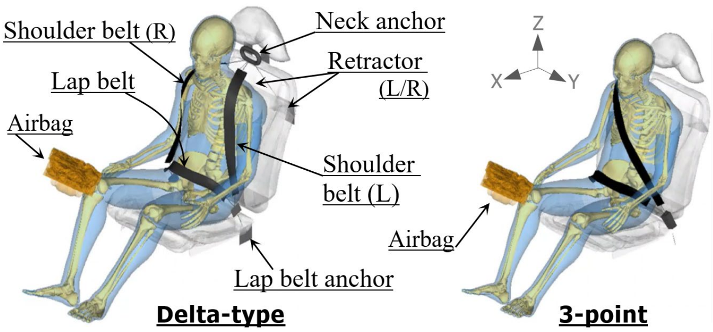

Fig. 1 Three-point and Delta-type Seat belt FE models.

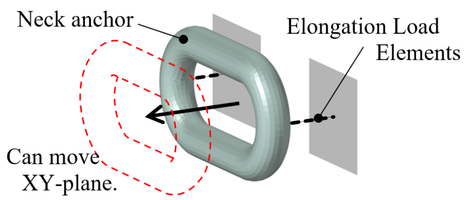

Fig. 2 Schematic diagram of the movable neck anchor and elongation load element mounted on the seatback upper section.

The standard three-point seat belt configuration with a retractor force limiter (FL) of 4 kN was used as the reference configuration for comparison (Case 3P-11). Cases D-11 and D-12 represent delta-type seat belt configurations in which the left and right belt retractors were assigned FL values of 1 kN each (2 kN in total) and 2 kN each (4 kN in total), respectively, together with neck anchor FL values of 2 kN and 4 kN, respectively. These values were determined based on our previous FE simulations[4]. The time-to-fire (TTF) was set to 13 ms.

The injury assessment indices comprised chest deflection, defined as the distance between the sternum and the spine; and the axial compressive force and bending moment about the lateral axis at T12/L1, expressed in the local spinal coordinate system. For the head, the rotational velocity about the lateral axis was compared to evaluate the effect of bilateral shoulders restraint on forward head rotation.

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III. INITIAL FINDINGS

Figures 3 and 4 show kinematics of THUMS and time-histories of chest deflection, and spinal force and moment. Chest deflection with the three-point seat belt reached 35.3 mm in compression. In the delta-type seat belt configurations, the bilateral shoulder restraint initially induced thoracic expansion, which was subsequently reversed to compression by airbag deployment.

The resulting compressive deflection remained small, at less than 15 mm. Spinal compressive forces were comparable across all seat belt conditions; however, the downward loading applied by the shoulder belts to the shoulder region elevated the spinal compressive force to a range of 2.6–2.8 kN. The three-point seat belt exhibited lower value for the spinal flexion bending moment. The upper torso showed a torsional motion about the superior-inferior axis due to the forward motion of the right upper extremity, suggesting that the flexion moment may be released and mitigated. In the delta-type seat belt, reduced lateral torsion allowed forward flexion to be more directly transmitted to the spine, resulting in a larger bending moment. In Case D-11, which employed a lower FL than Case D-12, the occupant's forward excursion was greater; nevertheless, chest deflection and spinal loading remained at comparable levels compared to those in Case D-12. The peak values of head rotational velocity about the lateral axis were consistent across all FE analyses.

TABLE I
SPECIFICATION OF EACH FE MODEL AND PEAK VALUES AT EACH BODY REGION

Case#	Seat belt	Ret. FL	Neck Anchor FL	Head Y Rot.V	Chest Def. Comp.	Chest Def. Expand	Spine T12/T1 FZ	Spine T12/T1 MY
D-11	Delta	1+1	2	59.4	14.7	14.7	2.63	243
D-12	Delta	2+2	4	60.8	13.4	16.6	2.80	252
3P-11	3P	4	---	59.7	35.3	0.0	2.62	116
		kN	kN	rad/sec	mm		kN	Nm

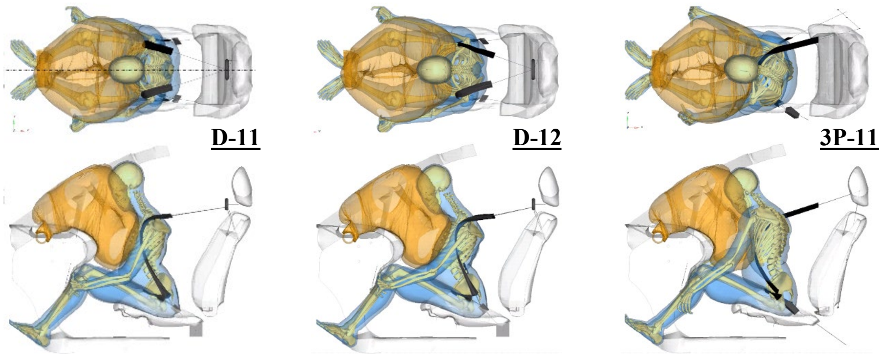

Fig. 3 Upper and left side view of kinematics in THUMS (72 ms).

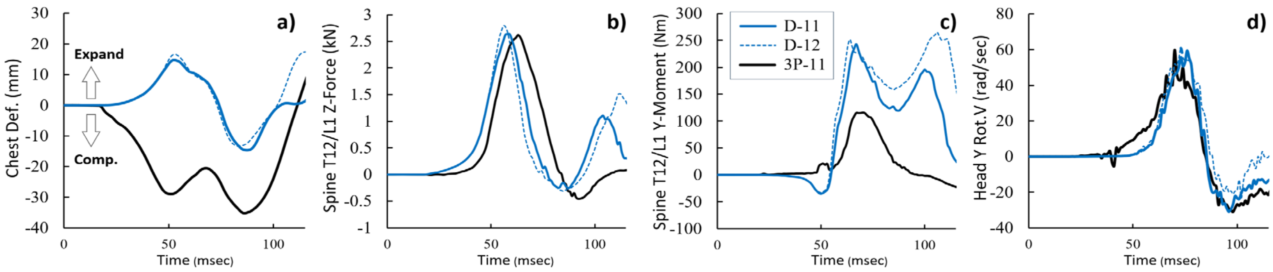

Fig. 4 Time-histories of THUMS: (a) Chest def., (b) Spine Z-force, (c) Spine Y-moment, (d) Head Y Rot.V.

IV. DISCUSSION

The delta-type seat belt yielded small chest loading in terms of chest deflection. Spinal compressive force was 2.63-2.8 kN in Cases D-11 and D-12, which was slightly higher than that of the three-point seat belt (2.62 kN). Though the shoulder belts applied compressive loading to both shoulders, which transmitted to the lumbar spine, the FL effectively reduced the lumbar spinal compression. This current study has shown that the delta-type seat belt can effectively reduce thoracic loading without substantial increase of spinal compression. Further investigation is needed for additional crash directions, occupant sizes, and postures. In particular, cervical loading in far-side impacts may be mitigated by setting a lower FL value to moderate occupant displacement, thereby reducing neck loading. In addition, the use of wearing delta-type seat belt also warrants discussion.

V. REFERENCES

[1] Kent R *et al.* , ESV, 2003.
[2] Mroz *et al.*, IRCOBI, 2018.
[3] Rouhana *et al.* , STAPP, 2003.
[4] Amamori *et al.*, JSAE, 2026