Cover protection for occupants of various body sizes via uniformly distributed restraint force

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I. INTRODUCTION

Studies have revealed that occupant sex, age, height and BMI could influence the protection effectiveness of restraint systems [1-2]. Females with smaller body sizes usually experience higher acceleration processes and have lower injury tolerance than males [3]. Adaptive restraint systems have been developed to provide individualised occupant protection via adjusting the restraint forces based on crash scenarios and occupant body sizes [4-5]. These adaptive restraint devices require extra controlling and operation systems, with increased cost. In this study, we proposed a strategy to use a uniform restraint pattern to provide protection for occupants of different body sizes using fixed restraint forces and compared it with state-of-the-art restraint systems via simulation.

II. METHODS

Conceptual design of uniform restraint pattern

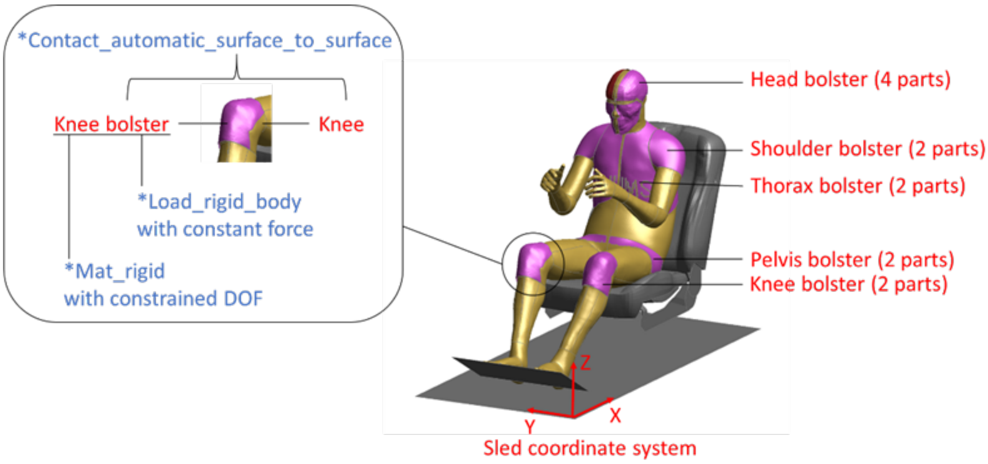

Fig. 1. Uniform restraint simulation platform with bolsters marked in pink on body surface.

The basic idea of *uniform restraint pattern* is to distribute restraint loads uniformly on the sturdy body regions, including head, shoulders, thorax, pelvis and knees, with proper magnitudes. A simulation platform was developed to realise the uniform restraint with a sled model in LS-DYNA (Fig. 1). On the sled, the THUMS (Version 4.0) occupant model was restrained by bolsters loading on the sturdy body regions. The bolsters were modeled as rigid parts consisting of shells with geometry morphed from the skin of the occupant model. The contacts between the occupant and the bolsters were defined by *contact-automatic-surface-to-surface, and initial gaps between the bolsters and the occupant skin were around 1 mm to ensure timely contact. In this study we focused on occupant protection in frontal crash, and the crash acceleration was only along the X direction in the local coordinate system of the sled. The external forces acting on the rigid bolsters by *load-rigid-body were only in the X direction and remained constant during the crash.

Simulation Matrix and Injury Metrics

THUMS 50^{th} percentile male (M50) and 05^{th} percentile female (F05) HBMs were restrained by four restraint patterns: 3-point seat belt (4 kN limit force); 3-point seat belt with airbag (6L); symmetrical double seat belts (2 kN limit force for each side); and our proposed uniform restraint system (head: 0.24 kN, shoulder: 0.8 kN, thorax: 1.8 kN, pelvis: 1.6 kN, knee: 1.0 kN for each bolster) in a 48 km/h frontal crash (Fig. 2). The symmetrical double seat belts restraint is a simplified modeling of 4-point seat belts by using two 3-point seat belts symmetrically.

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The restraint forces of each restraint pattern were fixed for both HBMs. Nodal and cross-sectional data were defined as outputs to monitor the kinematics of body segments. Injury metrics were calculated, including HIC15, BrIC, Nij, Cmax, cross-sectional forces of femurs (Fz_femur) and the corresponding probabilities of injuries above AIS2 or 3. These injury metrics were then summarised and normalised as the joint probability of all local injury risks [6]:

$$P_{joint} = 1-(1-P_{HIC})*(1-P_{BrIC})*(1-P_{Nij})*(1-P_{Cmax})*(1-P_{Femur})$$

III. INITIAL FINDINGS

Restraint patterns with more uniformly distributed restraint forces decrease the injury risks for both M50 and F05 HBM, and this decrease is more significant for F05 (i.e. the difference in injury risks between M50 and F05 decreases as the restraint forces distribute more uniformly) (Fig. 2(e)). The simulation result shows that the symmetrical loading can optimise occupants' in-crash motional behaviours by avoiding body twisting around the shoulder belt. Furthermore, the uniform restraint pattern releases the concentrated thoracic and abdominal deformation near the seat belts (Fig. 3), resulting in a significant reduction of the thoracic injury risk for F05.

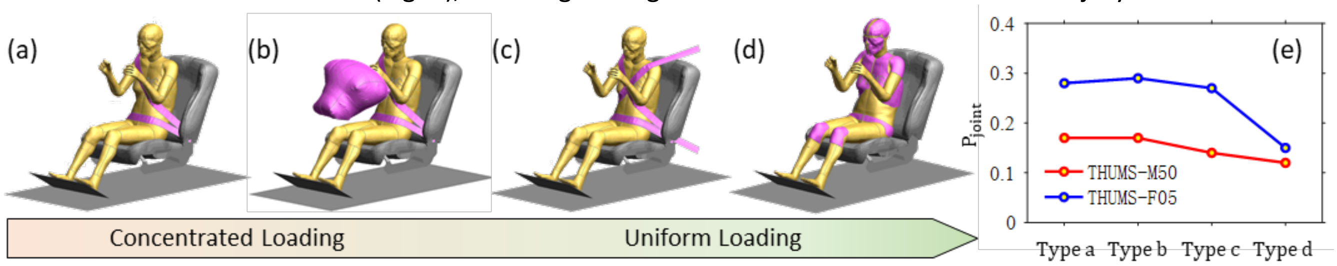

Fig. 2. (a) 3-point seat belt; (b) 3-point seat belt with airbag; (c) symmetrical double seat belt; (d) fully uniform restraint pattern; (e) joint injury probabilities for four restraint systems.

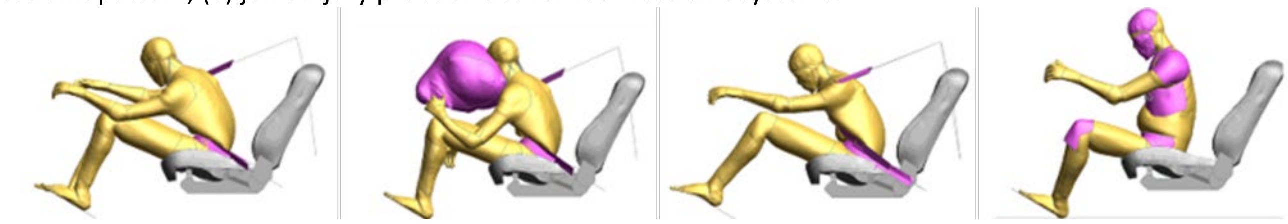

Fig. 3. In-crash motion postures of occupants with each restraint system.

IV. DISCUSSION

In this study, we demonstrated a conceptual design of uniform restraint pattern and preliminarily evaluated its performance in protecting different body-sized occupants by comparing it with some state-of-the-art restraint patterns. The uniform restraint pattern shows effectiveness in mitigating injuries and controlling motion postures for both occupants, which indicates the feasibility of designing a restraint system with fixed restraint forces to provide protection for occupants of various body sizes.

Based on this uniform restraint simulation platform, more parametric studies will be carried out to find the optimal restraint configuration to minimise the injury outcomes under given occupant body sizes, sitting posture, vehicle interior and crash scenario. The optimal restraint configuration can further guide the design of physical equipment. Although the practical implementation may not achieve the same level performance as the theoretical results, by designing new kinds of restraint patterns (shoulder bolsters, armpit supporters, etc.), we aim to enhance the protection in scenarios involving increased impact velocities and reclining postures.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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