Adaptive bumper towards scenario-specific pedestrian protection: conceptual design and preliminary evaluation of injury mitigation performance

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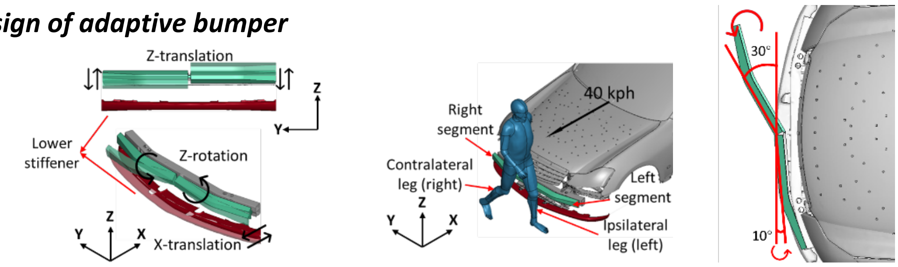
I. INTRODUCTION

Considering the reported pedestrian casualties in traffic accidents and the inevitability of vehicle-to-pedestrian collisions, even in future traffic, pedestrian safety remains a significant issue. Conventional vehicle bumpers have been optimized through changes in material and geometry following existing regulations, while studies have revealed that pedestrian lower-leg injuries vary with accident scenarios, e.g. impact orientation and contact locations [1-2]. Although future automated vehicles will be able to detect imminent crashes, it will not be possible to avoid all collisions as pre-warning time might be too short. To this end, we propose *adaptive bumper*, which can adjust its own configuration at a sub-system level when an unavoidable vehicle-to-pedestrian collision is detected, and consequently minimize pedestrian injuries. In this study, a conceptual adaptive bumper design is demonstrated, and its performance in mitigating lower-leg injuries is preliminarily evaluated through simulations.

II. METHODS

Conceptual design of adaptive bumper



(a) (b) (c)

Fig. 1. (a) Translation and rotation of bumper segments; (b) the simulation scenario; (c) an example configuration with 30° right segment rotation and 10° left segment rotation.

The basic idea is to identify injury-sensitive degrees of freedom (DOFs) and make the mechanism adjustable accordingly. The adaptive bumper system is shown in Fig. 1(a). Compared to a conventional bumper, the energy-absorbing foam block and an added supporting plate behind the foam as a whole is separable and adjustable from the main bumper beam, and the system is further split into two segments – left and right. Each segment is allowed to independently translate along the Z-axis and to rotate about the Z-axis relative to the main bumper beam. The lower stiffener is allowed to translate in the X-axis. See [3] for details of the conceptual design (patent pending). The rotation of segment is inspired by the prominent influence of impact orientation on knee injuries [2]; the Z-translation is for adjusting according to pedestrian height; while the X-translation of lower stiffener is to balance impact load distribution between tibia and knee joint by matching up with above segment's position.

Preliminary evaluation of adaptive bumper performance in injury mitigation

A validated sedan model from our previous study [4] is used to demonstrate and evaluate our design. The accident scenario is: at the bumper centre, the sedan laterally impacts a walking THUMS pedestrian model (AM50, V402) at 40 km/h. Simulations are carried out in LS-DYNA (LSTC, US). As a preliminary evaluation, only the rotation of each segment is varied, while the two translations (main bumper and lower stiffener) remain fixed and are not varied. In total, 21 cases were simulated in which the right segment rotation angle was changed at every 5° within 0–30° range and the left segment was at 0°, 5° and 10°, respectively.

Resultant forces at the mid-substance of MCL, ACL and PCL, as well as resultant bending moment at mid-shaft of tibia, are calculated to assess the risk of ligament rupture and bone fracture. Concerning monotonicity of ligament tissue's constitutive model, resultant force, principal strain and elongation are equivalent in terms of assessing the ligament stretch. All tissue failures are toggled off. We intend to focus on the trend of change in risks rather than absolute values.

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III. INITIAL FINDINGS

Compared to the original configuration (0° rotation of both segments), some appropriate combinations of right segment angle and left segment angle can successfully bring down the peak values of the injury metrics. The ipsilateral leg, impacted by the left segment (Fig. 1(b)), is more sensitive to its configuration. Thus, for a given right segment angle, we plot the injury metrics of the ipsilateral leg against change of the left segment angle (Fig. 2(a)) and find all metrics reduced. In particular, the ACL force is reduced by 16.5%. Similarly, the contralateral leg is more significantly influenced by the right segment. Fig. 2(b) shows the injury metrics of the contralateral leg varied with the right segment angle. When the left segment angle is fixed at 10°, the contralateral ACL and PCL forces can be significantly lowered when the right segment rotation is greater than 15° and the MCL force remains at a low level. The tibia moment increases slightly but is still below the failure threshold (about 300 Nm [5]), thus, the tradeoff is considered as acceptable in this case.

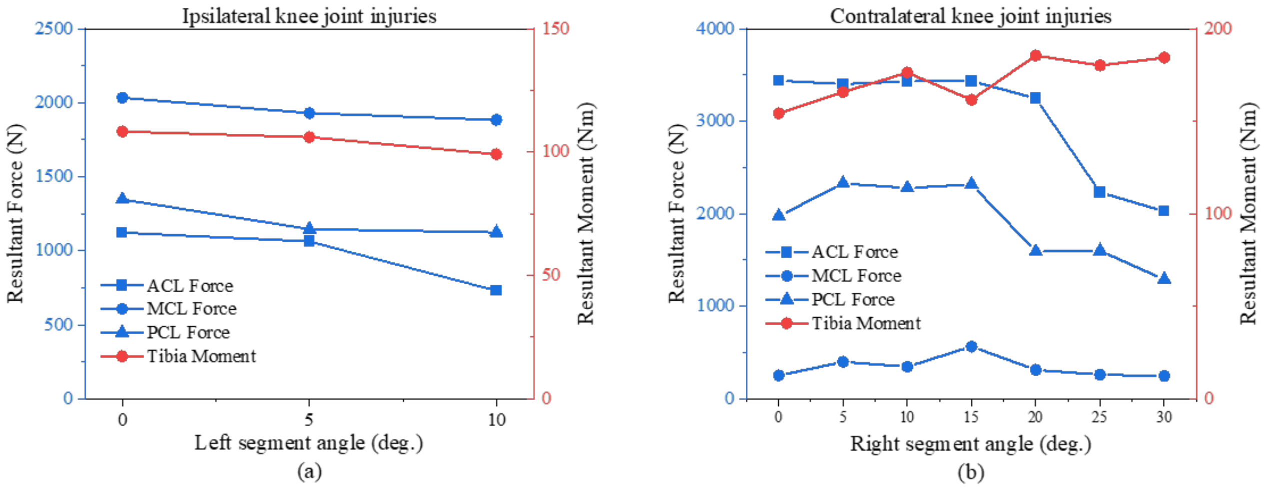

Fig. 2. (a) ipsilateral knee injuries with 0° right segment rotation; (b) contralateral knee injuries with 10° left segment rotation.

IV. DISCUSSION

In this study, under one impact condition of vehicle-to-pedestrian collision we demonstrated a conceptual design of an adaptive bumper and preliminarily evaluated its efficacy in reducing injury risks of lower extremities. By adjusting the segment angle relative to the position and posture of pedestrian, locally it transforms the impact from lateral to rearward and 'unloads' the legs by triggering the natural bending of knees and, consequently, reduces rupture risk of knee ligaments [2]. Adaptive bumper can become an active protection measure for automated vehicles. Upon receiving collision warning, physically adjusting segments (translation and/or rotation) usually takes less than 1s [3], while a typical pre-crash warning time is 1-2s when a possible collision is detected. Even if prediction does not reach satisfactory accuracy, or no configuration change can reduce injury risks, the adaptive system can always choose not to act.

Next, we will simulate a larger matrix, including more impact severities, body sizes, postures and configurations of the adaptive bumper system, to build a robust strategy for active protection. Predictably, a global optimal configuration for reducing all injury metrics may never exist. Where a conflict arises, the system shall always endeavor to mitigate the most severe and life-threatening injuries at top priority.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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