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Injury tolerance of tibia for the car–pedestrian impact

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ABSTRACT

Lower limbs are normally the first contacted body region during car–pedestrian accidents, and easily suffer serious injuries. The previous tibia bending tolerances for pedestrian safety were mainly developed from three-point bending tests on tibia mid-shaft. The tibia tolerances of other locations are still not investigated enough. In addition, tibia loading condition under the car–pedestrian impact should be explored to compare with the three-point bending. This work aims to investigate the injury tolerance of tibia fracture with combined experimental data and numerical simulation. Eleven new reported quasi-static bending tests of tibia mid-shaft, and additional eleven dynamic mid-shaft bending test results in the previous literature were used to define injury risk functions. Furthermore, to investigate the influence of tibia locations on bending tolerance, finite element simulations with lower limb model were implemented according to three-point bending and pedestrian impact conditions. The regressive curve of tibia bending tolerance was obtained from the simulations on the different impact locations, and indicated that tibia fracture tolerance could vary largely due to the impact locations for the car–pedestrian crash.

1. Introduction

The pedestrian is one of the most vulnerable road users around world, in overall France, the 2008 accidental data show that pedestrian injuries accounted for approximately 13.6% of total traffic road injuries, with 580 fatalities of these victims (ONISR, 2008). Although rarely fatal, lower limbs have been found in many studies to be the most common injured body part of pedestrian, followed by the head injuries as a close second (IHRA, 2001, Cater et al., 2008). Moreover, it was also reported that lower limbs injuries of pedestrians cost cumulatively more than any other body regions (Richards et al., 2009). In addition, lateral blunt impact with the bumper has been identified as the most common cause for tibia injuries (Yang, 2005). However, the detailed influence of bumper on the tibia structural response is still unknown.

The bending tolerance of tibia bone structure has been globally reported in the previous studies. For example, Yamada (1970) summarized tibia static bending tests conducted by Motoshima in 1960 with average fracture tolerance 184 Nm, which indicated that the female has five-sixths tibia bending strength of the male, and the fracture bending moment varies negligibly between the anterior–posterior and lateral–medial direction. In the reported tests of this study, the significant variances of bending tolerance due to impact directions were also not found. For dynamic bending, Nyquist et al. (1985) reported that mid-shaft fracture of the tibia occurred at bending moments of about 280 and 320 Nm for females and males, respectively, regardless of the impact directions. And Nyquist et al. (1985) also indicated that X-ray films of pedestrian victims commonly show classical tibia fracture patterns similar to bending failures of brittle beams. Hence, tibia bone structure could be assumed as a simple cylindrical beam under bending regardless of loading directions. In addition, according to recent studies (Ivarsson et al., 2004, 2005), the loading responses of the legs to lateral–medial bending depended highly on loading locations. Thus, research on tibia tolerances of different locations could be necessary.

Several tibia injury risk functions were developed from the existed test results. Kuppa et al. (2001) summarized the tibia injury criteria, and indicated that tibia index was an injury risk function considering combined bending and axial compressive loading on tibia. Then, the revised tibia index was developed from the tibia index equation based on bending test data in the literatures (Nyquist et al., 1985; Schneider and Crandall, 1997). Recently, Kerrigan et al. (2004) scaled the dynamic three-point bending test data from several studies based on a reference geometry to develop injury risk functions for pedestrian lower extremities. However, only test data from dynamic mid-shaft bending were included in the injury risk function of leg, and the influence of scaling method was also not been discussed. The validity of these injury risks functions could not remain available when bending appears

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