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Investigation of head injuries by reconstructions of real-world vehicle-versus-adult-pedestrian accidents

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Abstract

A sizeable proportion of adult pedestrians involved in vehicle-versus-pedestrian accidents suffer head injuries, some of which can lead to lifelong disability or even death. To understand head injury mechanisms, in-depth accident analyses and accident reconstructions were conducted. A total of 120 adult pedestrian accident cases from the GIDAS (German in-depth accident study) database were analyzed, from which 10 were selected for reconstruction. Accident reconstructions initially were performed using multi-body system (MBS) pedestrian and car models, so as to calculate head impact conditions, like head impact velocity, head position and head orientation. These impact conditions then were used to set the initial conditions in a simulation of a head striking a windshield, using finite element (FE) head and windshield models. The intracranial pressure and stress distributions of the FE head model were calculated and correlated with injury outcomes. Accident analysis revealed that the windshield and its surrounding frames were the main sources of head injury for adult pedestrians. Reconstruction results indicated that coup/contrecoup pressure, Von Mises and shear stress were important physical parameters to estimate brain injury risks.

Keywords: Pedestrian safety; Accident reconstruction; Head injury; Mathematical simulation

1. Introduction

In vehicle-versus-pedestrian accidents, head injuries are one of the most common injury types, and can lead to lifelong disability or death. When International Harmonized Research Activities (IHRA) investigated and analyzed 1605 pedestrian accidents in Australia, Germany, Japan and the USA, head injuries accounted for 31.4% of 3305 AIS2+ injuries (IHRA, 2001). Maki and Kajzer (2003) reviewed the pedestrian accident cases in Japan from 1995 to 1998, and found that 22% of serious injuries and 64% of fatal injuries were head injuries which indicated that the odds to be fatally injured were 6.3 times as high when sustaining a head injury relative to when sustaining other injuries.

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The most common types of head injury sustained in pedestrian accidents are scalp and facial tissue injuries, including abrasions, contusions, and lacerations. Otte (1999) reported that 91% of 543 injured pedestrians suffered soft tissue injuries to the head. Although soft tissue injuries are common in pedestrian accidents, they generally rate low in terms of AIS level, and are not life-threatening. The other two head injury types observed are skull fractures and brain injuries. Harruff and Avery (1998) performed a retrospective analysis of 217 pedestrian fatalities with a total of 378 severe (sometimes multiple) head injuries in the USA. Among these injuries, 150 were skull fractures and the remaining 228 were brain injuries. It was found that the relative frequency of vault and skull base fractures was related with injury severity. The frequency ratio of vault to basal fractures was calculated as 2.74, based on Otte's study, among which 39% were MAIS2+ head injuries (Otte, 1999). This ratio changed to 0.70 when only fatally injured pedestrians were investigated (Harruff and Avery, 1998). These figures indicated that the odds to be killed in case of a skull base fracture were 3.9 times as high as in case of a vault fracture. Concussion is a common type of brain injury in pedestrian accidents. Mild concussions (AIS2) can lead to confusion, disorientation, and minor loss of memory. Although the injury mechanisms for concussions remain uncertain, clinical investigations have found that a concussion was a disorder of function, rather than structure (Verjaal et al., 1975; Ropper, 1994). In this study, AIS3+ brain injury risk was examined, since AIS3+ brain injuries are severe and irreversible.

Over many decades, head injury mechanisms among vehicle occupants have been widely investigated, leading to many important findings. However, these results cannot be used directly to protect pedestrian heads, since the conditions under which a pedestrian's head becomes injured are quite different from those of an occupant (Yang, 2003). Pedestrian heads suffer both a direct impact with stiff vehicle structures and a large degree of rotational acceleration. The distribution of impact points also differs, with the pedestrian's head more likely struck on its posterior or lateral aspect versus the predominantly frontal impacts that occur among car occupants (McLean et al., 1996a,b; Yang, 2005).

The primary aim of the current study was to investigate head impact conditions and to understand head injury mechanisms in pedestrian accidents. This knowledge is the prerequisite for the improvement of car front structures.

2. Method and materials

An in-depth accident analysis was first conducted to understand head injury related collision characteristics. In order to determine head impact conditions, accident reconstructions were then conducted using MBS models. The estimated head impact conditions were applied as initial conditions in an FE head model, so as to estimate injury tolerance levels by physical parameters, like intracranial pressure and stress.

2.1. Accident data collection

In the district of Hanover, Germany, a representative sampling of traffic accidents was carried out by order of the German Government, in cooperation with car manufacturers (Otte et al., 2003). These accident cases were documented in the accident database GIDAS (German In-Depth Accident Study) by the Accident Research Unit at the Medical University of Hanover. The cases collected in the GIDAS database contain detailed information regarding vehicle, victim and environment during the pre-crash, crash, and post-crash phases. A total of 120 passenger car-to-pedestrian accident cases were analyzed from the GIDAS database. One case from the GIDAS database is used here as an example, to illustrate the extent of the accident information provided by the GIDAS database.

The example case happened on a residential street in Hanover, Germany (Fig. 1a). The involved vehicle was a 1993 Golf III, which was travelling along the residential street. The involved pedestrian was a 70-year-old man who emerged quickly from behind a building on the right side of the passenger car and proceeded to cross at a designated pedestrian crossing. Due to obscured view by the building, the driver was unable to see the man until it was too late. As soon as the driver did notice the man, he braked hard; nonetheless, the car struck the elderly man at an estimated speed of 43 km/h.

The car's bumper struck the man's left leg and the car's windshield struck the man's head. Scratches and other damage to the car are shown in Fig. 1b. The contact points on the car were measured using an x,y,z